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TECHNICAL TRANSLATION

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DRIFTS AND IRREGULARITIES IN THE IONOSPHERE

Chief Editor, S. F. Mirkotan; Editor, A. D. Podol'skiy;
Technical Editor, V. V. Bruzgul'

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TABLE OF CONTENTS

5. Moscow (IZMIRAN - Research Institute for Earth Magnetism and Radiowave Propagation of the Academy of Sciences USSR), since July 1957. North 55° 28', East 37° 19'.

6. Simeiz (FIAN - Institute of Physics of the Academy of Sciences USSR Imeni P. N. Lebedev), since December 1957. North 44° 24', East 33° 59'.

7. Tomsk (SFTI - Siberian Physics and Technology Institute), since September 1957. North 56° 28', East 84° 56'.

8. Khar'kov (KhPI - Khar'kov Polytechnic Institute), since August 1957. North 49° 26', East 36° 55'.

Somewhat later, this network of stations was expanded by the addition of observation points located in Murmansk and Rostov-on-the-Don.

At Moscow University, observations of large-scale irregularities in the F-2 layer (extending over dozens and hundreds of kilometers) are performed by the phase method. A steric (three-dimensional) spaced recording is effected at 3 points, which form a measuring triangle with 30-60 km-long sides. The recorded data are processed by means of a correlation analysis. At the other stations, winds are recorded by the amplitude method, involving a steric spaced recording with a small base (of approximately 100 m), i.e., small-scale irregularities, extending over dozens or hundreds of meters, are studied. At the same time, successive observations of the E and F-2 layer are performed. The equipment available at the Simeiz station makes it possible to perform simultaneous recordings of the E and F-2 layers. The so-called method of similar fadings is used in the study of small irregularities; the correlation method is used for control and checking purposes.

The results of preliminary studies of winds and of the parameters of an irregular ionosphere, obtained at various Soviet stations, were present at the 5th Meeting of the Special IGY Committee, held in Moscow in August 1958 (see the paper read at the symposium by L. V. Grishkevich, V. D. Gusev, Yu. V. Kushnerevskiy, S. F. Mirkotan, Ye. G. Proshkin, entitled "Preliminary Results of Studies of an Irregular Ionosphere and Ionospheric Movement Conducted at Soviet Stations During the IGY Period".

The present collection of articles presents the principal results of observations conducted at the Ashkhabad, Moscow (Moscow State University and IZMIRAN), Tomsk and Khar'kov stations. Sufficiently extensive and systematic data dealing with the study of ionospheric irregularities have been obtained mainly during the 1957-1958 period. This monograph also includes an article devoted to the study of ionospheric irregularities, conducted by means of radioastronomic methods at the Simeiz station, which was performed at a somewhat earlier date.

The simultaneous publication of results obtained at the above stations is undoubtedly of great scientific interest. An important point in this connection is the fact that the geographical distribution of these stations is characterized by significant differences in their latitude and longitude coordinates. In addition, it is possible to compare the results of observations of ionospheric movements, derived from a study of small-scale and large irregular formations based on the use of various methods (phase, amplitude methods, etc.). It is also necessary to point out certain differences in the methods used for the analysis and presentation of data. The simultaneous publication of the articles included in this monograph will permit to effect a comparison and a selection of the most general and successful methods, in order to provide in the future a better way of effecting a mutual comparison of these methods.

RESULTS OF THE STUDY OF PARAMETERS OF LARGE-SCALE IONOSPHERIC IRREGULARITIES BY THE PHASE METHOD (See Note)

V. D. Gusev, S. F. Mirkotan, L. A. Drachev,
Yu. V. Berezin and M. P. Kiyanovskiy

Abstract

The paper presents the main results of the study of parameters of the F-2 layer large-scale irregularities (Moscow, State University; 55° 42' N, 37° 33' E). The method of reception sounding was applied. The base of reception was 30-40 km. The variations of reflected signals phase path were registered in three points. Due to high precision of the registration it was possible to apply correlation analysis, developed earlier for small-scale irregularities, in the study of the large-scale irregularities. The results of the observations are given for the period from January 1957, till May, 1958.

The study of large-scale irregularities showed the presence of considerable anisotropy of form in the ionospheric irregularities. Mainly N-S direction of the great axis of anisotropy has been observed. The most frequent proportion of the axes of anisotropy is $e = 1.5 \div 2.0$. The proportion e and the direction of the great axis of anisotropy depends very little on the time of the day. The mean size of the irregularities along the small axis changed between day and night from 110 to 200 km, and along the big axis from 200 to 500 km respectively.

The results of observation showed that the most probable value V_d is $V_d = 130 \div 170$ m/sec. V_d is the velocity of the drift obtained as a result of complete correlation analysis, taking anisotropy into consideration. A 24-hour dependence of direction V_d has been determinated: at night to the North, during the day to the South, in the morning in

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[Note: Preliminary results of studies, published earlier in (1,2), are clarified and supplemented to a considerable extent in the present article. The method used for recording the phase of a signal reflected by the ionosphere and the instruments used for that purpose are described in (3,4)].

the SSE direction, in the evening in the NNW. The mean period of life for large-scale irregularities $\overline{\tau}_c = 4 \cdot \overline{\tau}_{05} \left(\frac{V_c}{V'_c}\right)$ changed from 15 min (day) to 30 min (night). τ_{05} is the time radius of correlation; V' is the characterized speed, and V_c is the speed of spreading.

The results obtained in this investigation are analyzed and compared with the results of other authors.

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1. Measuring Method and Processing of Original Data

A system consisting of 3 stations, which formed a measuring triangle, was used in studying large-scale irregularities in the F-2 layer. The parameters of the measuring triangle and its orientation in regard to the geographical and magnetic meridians are shown in Figure 1. Each station, with the aid of its transmitter, performs a vertical sounding (probing) of the ionosphere and records the phase variations of a pulse signal reflected by the F-2 layer. The data obtained in this manner consist of 3 photo films carrying the recorded variations of the phase path at each of the measuring stations. Samples of such recordings are illustrated in Figure 2. Track (a) is a recording of the variations in the phase path, and track (b) is used for recording temporary marks every other minute. Each "saw" corresponds to a 2π change in the phase path (per wavelength), while the positive or negative inclination of the "saws" is determined by a growth or reduction of the phase. The time marks are recorded by a contact chronometer, located at one of the stations, and are transmitted to other stations by means of radio relay communication lines. In order to correlate the beginning of time recording, a coded mark is transmitted every hour (mark c in Figure 2). The correlation of the mutual phase recordings is performed with an accuracy of several fractions of a second. The duration of minute time marks is equal to 2 seconds.

The processing of the photo films consists in counting the number of 2π (or λ) phase variations occurring during one minute. These figures are compiled into a 3-line table, whereby each line gives the magnitude of $\Delta\varphi$ per minute for the corresponding station. This table listing the values of $\Delta\varphi$, which will be later designated as φ', is the basic table used for processing data by means of an electronic computer in order to obtain correlation functions, as well as for plotting graphs of φ' (t) and φ (t) functions. φ (t) as a function of time is obtained by consecutive addition of φ' (t), taking the sign of the function into consideration. A table is drawn up for φ (t), which is analogous to the φ' (t) table. Each of these tables lists 240 values of φ and φ' for each station.

Thus, further processing covers a 4-hour recording interval (240 minutes). An interval of this size is necessary in order to allow the inclusion of a sufficiently large number of phase variations, or, in other words, to allow a sufficiently large selection of data (5). The processing of data, with a variation in interval duration of 2.5 to 4 hours, has shown that a 4-hour interval is sufficiently great in most cases. An analysis of the φ (t) and φ' (t) graphs, samples of which are illustrated in Figures 3 and 4, shows that a variation of the phase path is due not only to the presence of accidental irregularities, but also to regular daily variations of the layer. For this reason, a direct processing of φ (t) yields not only a correlation function of accidental variations in the phase path, but also a correlation function of regular daily variations. The method for calculating the sliding average was used, in order to eliminate the effect of daily variations and isolate accidental fluctuations of φ and φ' functions. F20

If the initial magnitudes of the φ and φ' functions are expressed in the form of consecutive values

$$x^*_j,\ y^*_j,\ z^*_j, \quad j = 1,\ 2,\ \ldots,\ 240.$$

then, in order to calculate the correlation functions, one can use the sequences of x_j, y_j, z_j values derived from the following relations:

$$x_i = x^*_i - \tilde{x}^*_i,$$

$$y_i = y^*_i - \tilde{y}^*_i,$$

$$z_i = z^*_i - \tilde{z}^*_i,$$

$$i = 1, 2, \ldots, n^{\mu}, \quad n^{\mu} = n - \mu,$$

where

$$\tilde{x}^*_i = \tilde{x}^*_{j+\frac{\mu}{2}-1} = \frac{1}{\mu}\sum_{j}^{j+\mu-1} x^*_j,$$

(formula continued)

$$\tilde{y}^*_i = \tilde{y}^*_{j+\frac{\mu}{2}-1} = \frac{1}{\mu}\sum_{j}^{j+\mu-1} y^*_j,$$

$$\tilde{z}^*_i = \tilde{z}^*_{j+\frac{\mu}{2}-1} = \frac{1}{\mu}\sum_{j}^{j+\mu-1} z^*_j, \quad j = 1,2,\ldots,n.$$

The calculation of auto- and mutual correlation functions is accomplished with the aid of the formula:

$$\rho^{\mu k}_{uv}(\tau) = \frac{\dfrac{1}{n^\mu_k - |\tau|}\displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} u_\lambda v_{\lambda+\tau} - \left(\dfrac{1}{n^\mu_k - |\tau|}\right)^2 \displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} u_\lambda \sum_{\lambda=1}^{n^\mu_k - |\tau|} v_{\lambda+\tau}}{\sqrt{\left[\dfrac{1}{n^\mu_k - |\tau|}\displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} u^2_\lambda - \left(\dfrac{1}{n^\mu_k - |\tau|}\displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} u_\lambda\right)^2\right]\left[\dfrac{1}{n^\mu_k - |\tau|}\displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} v^2_{\lambda+\tau} - \left(\dfrac{1}{n^\mu_k - |\tau|}\displaystyle\sum_{\lambda=1}^{n^\mu_k - |\tau|} v_{\lambda+\tau}\right)^2\right]}},$$

where

$$n^\mu_k = n^\mu - k \cdot 15, \quad k = 0,2,4,6,8.$$

The variation of the index μ makes it possible to change the interval of the sliding average, which is indispensable in order to clarify the rate of elimination of regular daily variations and the effect exerted by averaging at this interval upon the distortion of the random portion of the φ and φ' functions. Changes in the index k permits to vary the entire processing interval in order to establish whether the magnitude of this interval is sufficiently great. A variation of 2 units in the value of k corresponds to a 30 minute variation in the observation range.

A complete calculation program of correlation functions was conducted for the following values of u, v, μ, k and τ indices: $u, v = x, x; y, y; z, z$ - autocorrelation functions, with $\tau = 0,1,2,\ldots,30$ min; $u, v = x,y; xz; yz$ - mutual correlation functions, with $\tau = -12, -11,\ldots, -1, 0, 1,\ldots 11, 12$ min.

The horizontal dimensions of the irregularity, measured in the direction of the long and short axis, were determined from the relation:

$$\Delta = 4 \cdot V'_c \cdot \tau_{05}$$

where V'_c was measured in the direction of the long and short axis of the ellipse. The factor 4 was used in order to determine the horizontal dimension as the distance between the maximum and minimum. In case of a periodic variation, $4\,\tau_{05} = \tau_{min}$. In most cases, this relation is fulfilled. However, it is not always possible to establish the minimum value of autocorrelation functions. F

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Finally, the parameters τ_c and V_c/V were determined to evaluate 0
the role played by random variations of irregularities. The parameter τ_c can be derived from the relation $\tau_c = 4 \cdot \tau_{05} \cdot V'_c/V_o$, and characterizes the blurring ("bleeding") period of the irregularity. The parameter V_c/V_d, which is the ratio between the velocity of random variations and the drift velocity, permits to evaluate the role played by random variations.

2. General Characteristics of the Obtained Results

The results listed below apply to the F-2 layer. Preliminary measurements were conducted since 1956. Regular measurements, conducted at the rate of once a week, were started in January 1957. The duration of constant weekly observations varied from 24 to 76 hours. Since July 1957, regular observations are conducted in accordance with the IGY program for the measurement of drifts in the ionosphere (15). In addition to regular world days, the work schedule included supplemental days recommended for Soviet stations engaged in the study of drifts.

The present article gives the results of studies conducted during the period of January 1957 to May 1958.

During the above period, 60 sessions were conducted, each including constant observations lasting from 24 to 76 hours. For various reasons, not all recordings are suitable for processing purposes. A total of 101 recording intervals, each of 4-hour duration, were processed.

In order to establish the daily variations in parameters, all intervals were divided into 4 groups according to the time of the day : night - from 00 to 06 hours, morning - from 06 to 12 hours, day - from 12 to 18 hours, and evening - from 18 to 24 hours. The time was statutory Moscow time.

Distribution histograms were plotted for all analyzed magnitudes within each daily group, as well as daily diagrams of the average values of these magnitudes. Such an analysis included the following parameters of irregularities:

a. The axis ratio of the characteristic ellipse (e).

b. The angle formed by the large axis and the geographic meridian (a).

c. The horizontal size of irregularities, measured in the direction of the small and large axis Δ_{min} and Δ_{max}.

d. The magnitude V_d and the direction (angle β) of the drift velocity, and the corresponding magnitudes $V'_{\perp}$ and $\beta_{\perp}$.

e. The time characteristic of irregularities τ_{05}.

f. The relative blurring time of the irregularity:

$$\frac{4\tau_{05}}{\tau_c} = \frac{V'_c}{V_c}$$

As a preliminary analysis has shown, the shape of the histograms, as well as average values, do not vary a great deal when the parameter μ varies from 30 to 60. For this reason, the results listed below are given for $\mu = 60$. As was already noted above, an observation range of 4 hours duration was found to be sufficiently long from the standpoint of statistical processing. For this reason, data are further analyzed, in which k = 0 or 2, which corresponds to a processing interval of 3.5-4 hours.

An examination of the operation involving the recording of the daily course, and a comparison with the results based on the use of φ and φ', show that the optimum elimination (removal) of the daily course, with a minimum distortion of the random portion of these functions, can be achieved in the case of φ'. The results listed below therefore refer to this magnitude. Distribution histograms of the above mentioned parameters of irregularities are given in Figures 7-11. Each parameter is illustrated by 5 histograms: four histograms for each daily interval, and one common histogram covering a 24-hour period. All histograms are normalized, and the total number of cases is indicated in the corner of the corresponding histogram. The direction of the geographic meridian is given in the histograms of angles α, β and $\beta_{\perp}$.

light of the above-mentioned data, the modernization of this method appears to be expedient, for example, in a manner similar to (7), in order to take into account the presence of a substantial random variability of irregularities.

Thus, the main results of a study of large-scale irregularities in the F-2 layer can be summarized as follows:

1. The shape of irregularities in a horizontal direction is non-isotropic; the direction of the largest dimension (large axis of the characteristic ellipse) approximately coincides with the meridian; the average ratio between the large and the small dimension (axis ratio of a characteristic ellipse) is approximately equal to 2; this magnitude, as well as the direction of the large axis, is practically independent of the time of day; the average value of the large dimension is approximately equal to 500 km at night, and approximately 200 km during daytime.

2. The most frequently encountered values of the drift velocity of irregularities lie within a range of 8-10 km/min (130-170 m/sec); the direction of the drift is close to the meridian: in the evening and at night - towards the North, and in the morning and afternoon - towards the South.

3. The blurring of irregularities takes place at a slower rate at night and at a faster rate during daytime; the average random velocity is 1.5 times greater than the drift velocity.

3. Comparison of the Obtained Results With Formerly Known Results

The most detailed figures on the parameters of large irregularities are found in (6,8). The first study gives data on velocities, and the second - data on velocities and dimensions.

First, one should note the good agreement between the most frequently encountered values of drift velocity. According to data given in (6), this velocity lies within the range of 130-170 m/sec in July, and within the range of 90-130 m/sec in November, or 8-10 km/min accordingly. In (8), the same magnitude is equal to 140-160 m/sec, or 8.5-9.6 km/min. In (6), the apparent velocity was measured, without taking anisotropy into account, i.e., $V'_{\perp}$. The histogram of $V'_{\perp}$, obtained in studies performed by us, is shown in Figure 11.

It is difficult to make a comparison of the predominant velocity directions in view of the fact that they depend to a great extent upon the time of day. A break up of the velocity directions into various periods of the day is not given in (6) and (8). In regard to the horizontal dimensions given in (8), the order of magnitude and the type of distribution coincide. A detailed comparison is also made difficult in view of the absence of a daily break up.

A comparison of the behavior of $\beta_{\perp}$ (Figure 11) for large-scale and small scale (9) irregularities reveals a coincidence of the daily variations of these magnitudes. At the same time, a corresponding comparison of $\beta_{\perp}$ for simultaneously observed large and small irregularities also results in a good agreement between these magnitudes, although, as a rule, V_d - large is greater than V_d-small (9).

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The conclusion in regard to the presence in the ionosphere of a velocity of random variations substantially greater than V_d is confirmed by the studies described in (10), where $V_c/V_d = 1.8$.

The anisotropy parameters of (e) and α in irregularities of various scale also exhibit common laws in their behavior. Thus, in small irregularities, the variation of (e) lies within the range of 1-6, the value 1.5 being the one most frequently encountered; in 50% of the cases, the direction of the large axis is close to the magnetic meridian (11). A strong anisotropy ($e > 5$) was also detected by radio-astronomic methods for irregularities having a size of 1-10 km, and by the predominant direction of the large anisotropy axis along the magnetic meridian. (12).

The approximate evaluation of the lifetime of irregularities, based on the consideration of a diffusion process occurring under the conditions found in the F-2 layer (13), also agrees, in its order of magnitude, with the values of parameter τ_c obtained by us. This makes it possible to interpret the variability parameter τ_c as the period of life and blurring of large-scale irregularities.

Conclusion

The recording system and the calculation methods used for studying the parameters of large irregularities in the F-2 layer, described in the present article, have made it possible to obtain reliable information on the magnitude of these parameters and on certain laws concerned with changes in these parameters.

As a result of a high recording accuracy, the statistical system, developed earlier in order to study small irregularities, could be used successfully in studying large-scale irregularities. This is all the more important in view of the fact that, in order to study the dynamics of ionospheric processes resulting in the formation of an irregular ionospheric structure, it is highly important to obtain the greatest possible amount of varied and detailed information on irregularities.

For the above reasons, the coincidence of anisotropy, drift and random variation (blurring) factors is of definite interest, since this fact apparently points to a possible common nature of the processes controlling the formation and movement of all ionospheric irregularities.

The great importance of these results indicates the necessity of conducting more thorough theoretical, experimental and methodical studies.

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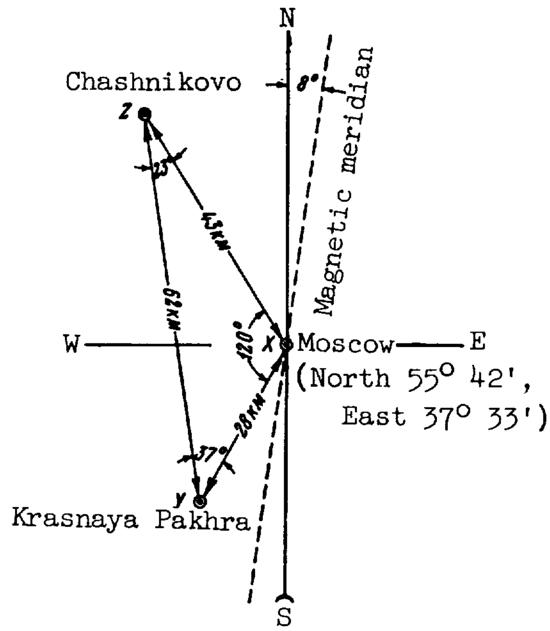

Figure 1.- Arrangement and parameters of measuring triangle used in steric-spaced recording; North-South - geographic meridian.

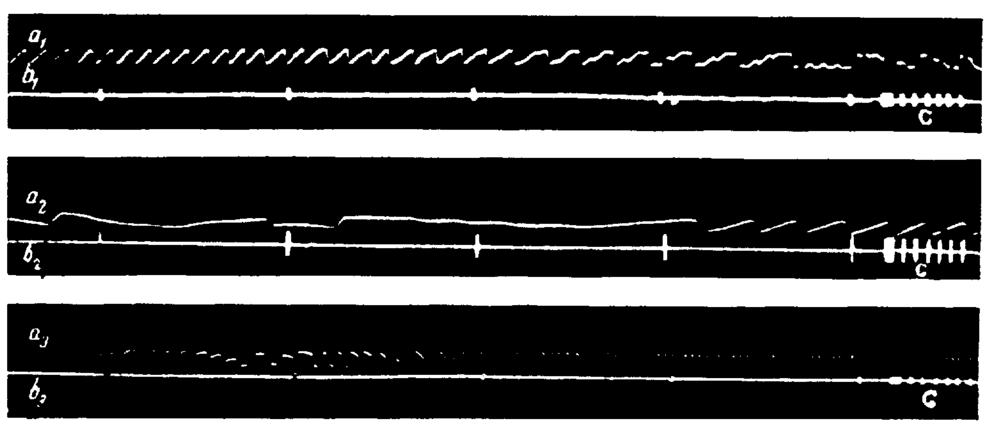

Figure 2.- Sample recordings showing variations in the phase path at 3 points: a - recording of variations in phase path; b - minute marks; c - hourly mark.

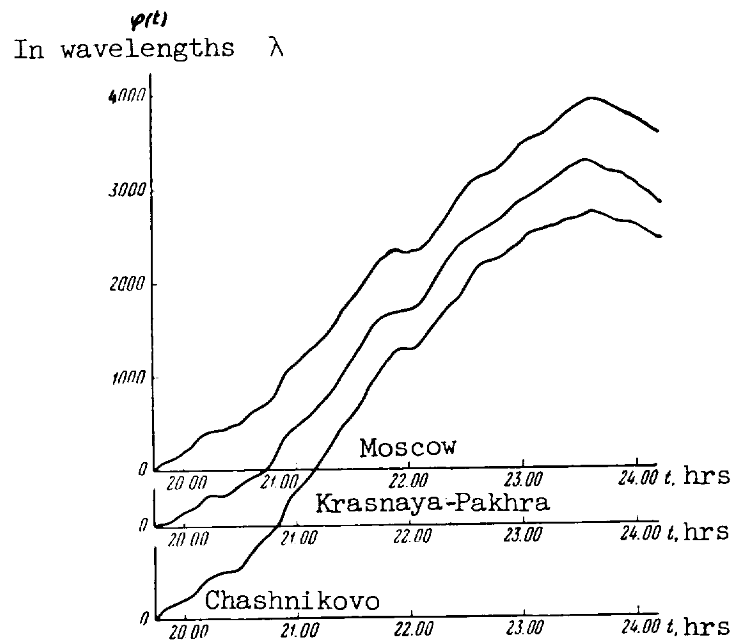

Figure 3.- Variations in phase path at three points, expressed as time functions. $\varphi(t)$ - expressed in wavelengths λ; Moscow time, statutory; F-2; f = 5.5 megacycles.

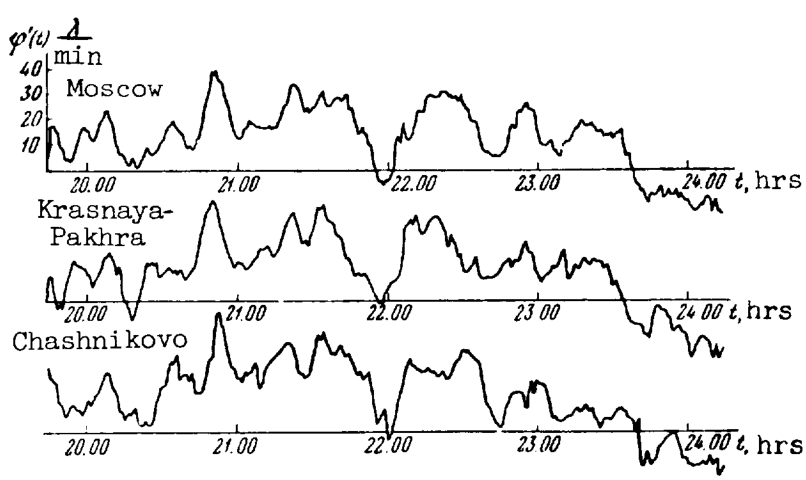

Figure 4.- Variations of $\varphi'(t)$ at 3 points as time functions. For $\varphi'(t) = \frac{\Delta\varphi}{\Delta t}$, a value of $\Delta\varphi$ per Δt = 1 minute was assumed; $\varphi'(t)$ is expressed in λ/min; F-2; f = 5.5 megacycles.

F-20

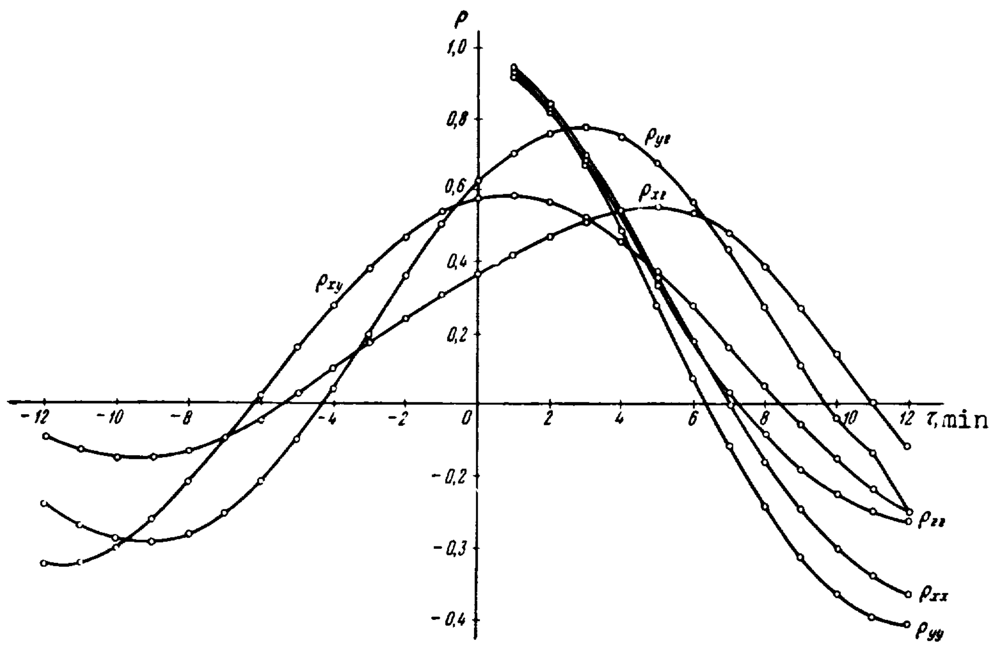

Figure 5.- Sample of auto- and mutual-correlation functions for a 4-hour interval. x, y, and z are indices of observation points according to figure 1.

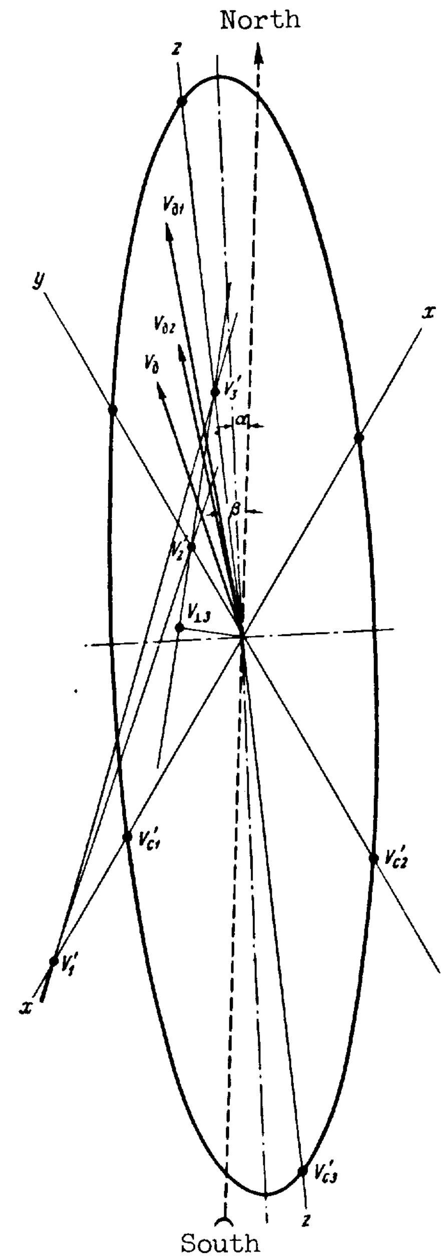

Figure 6.- Characteristic ellipse of the V'_c parameter, locations of the fronts of apparent velocities V', and directions of drift velocities V_d, plotted on the basis of the correlation functions shown in figure 5. xx, yy, and zz are directions of the sides of the measuring triangle; North-South - geographic meridian.

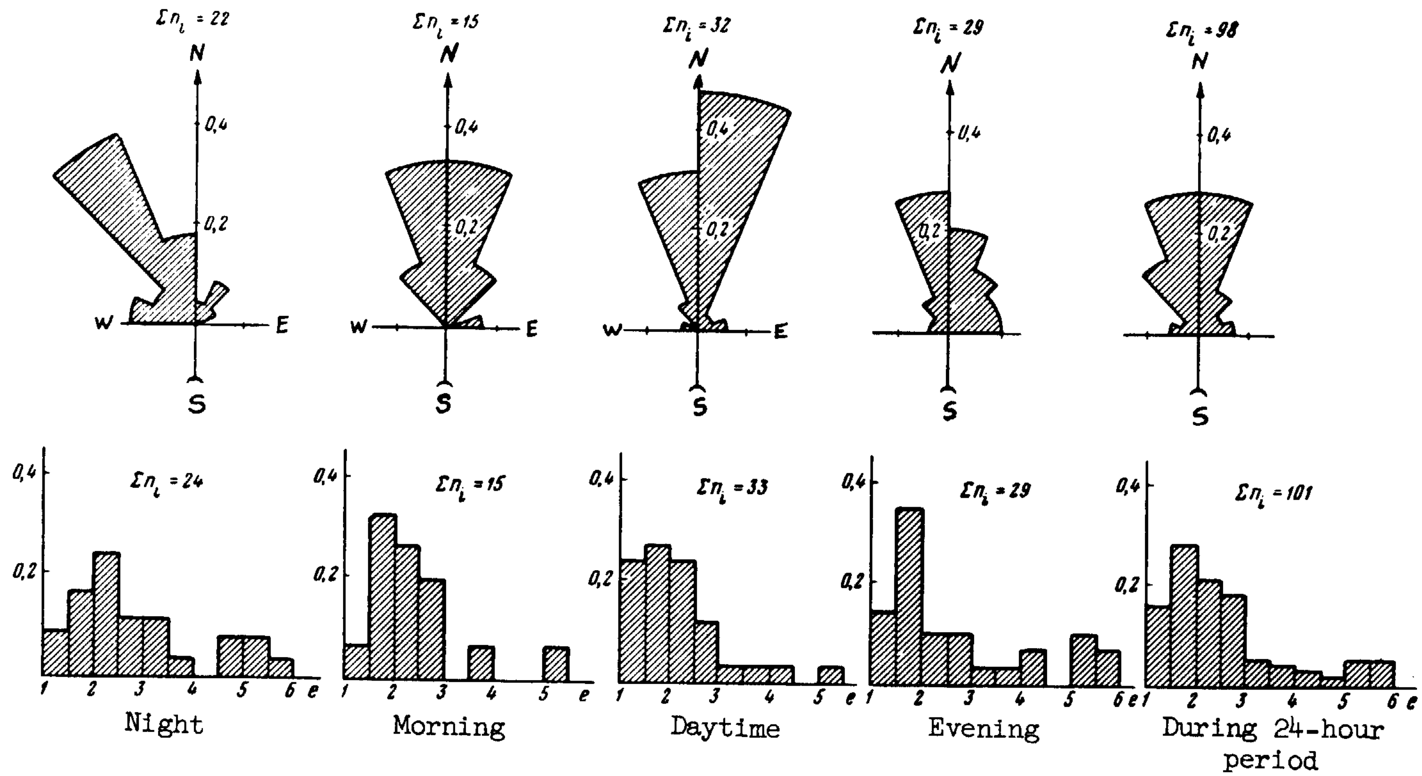

Figure 7.- Histograms of the values of angle α, formed by the large axis of the anisotropy ellipse and the geographic meridian, and histograms of the axis ratio in ellipse (e); F-2 layer. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axes and radii.

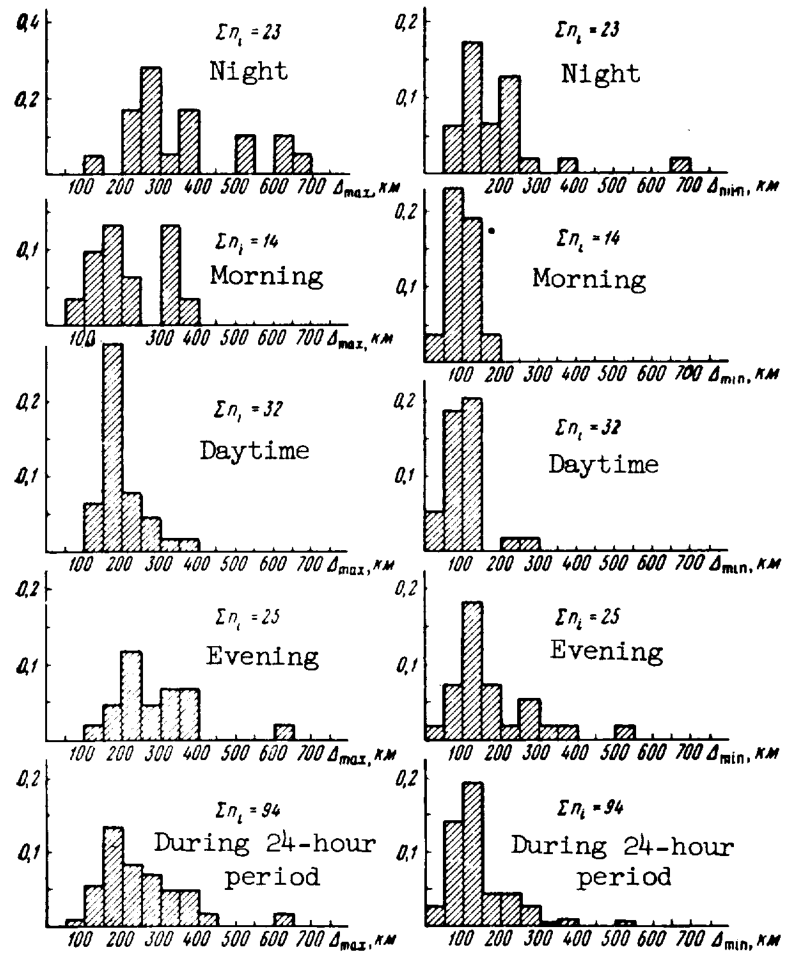

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Figure 8.- Histograms of horizontal dimensions of irregularities along the large (Δ_{max}, at left) and small (Δ_{min}, at right) anisotropy axes; F-2 layer. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axes.

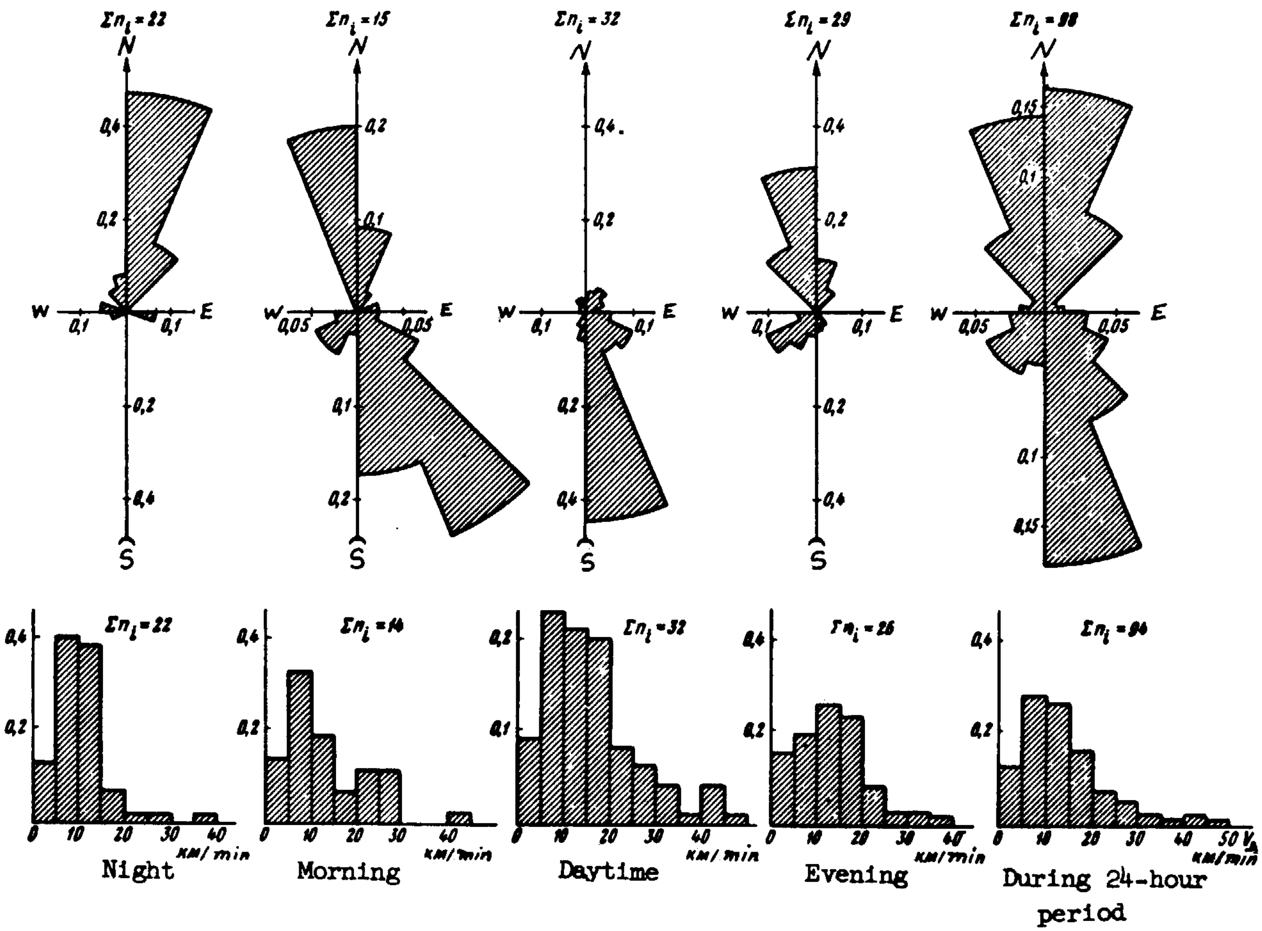

Figure 9.- Histograms of magnitude V_d and of the direction (angle β) of drift velocity, obtained by taking into account the anisotropy and the random variability of the diffraction pattern on the surface of the earth; F-2 layer. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axes and radii.

F-20

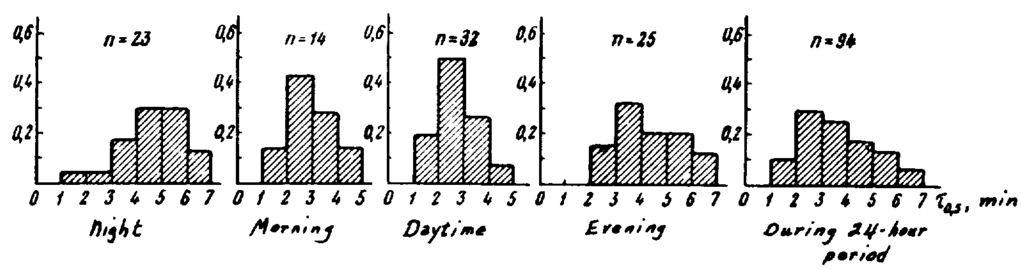

Figure 10.- Histograms showing the values of the temporary radius of the correlation $\tau_{05} \times \rho(\tau_{05}) = 0.5$; F-2 layer. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axes.

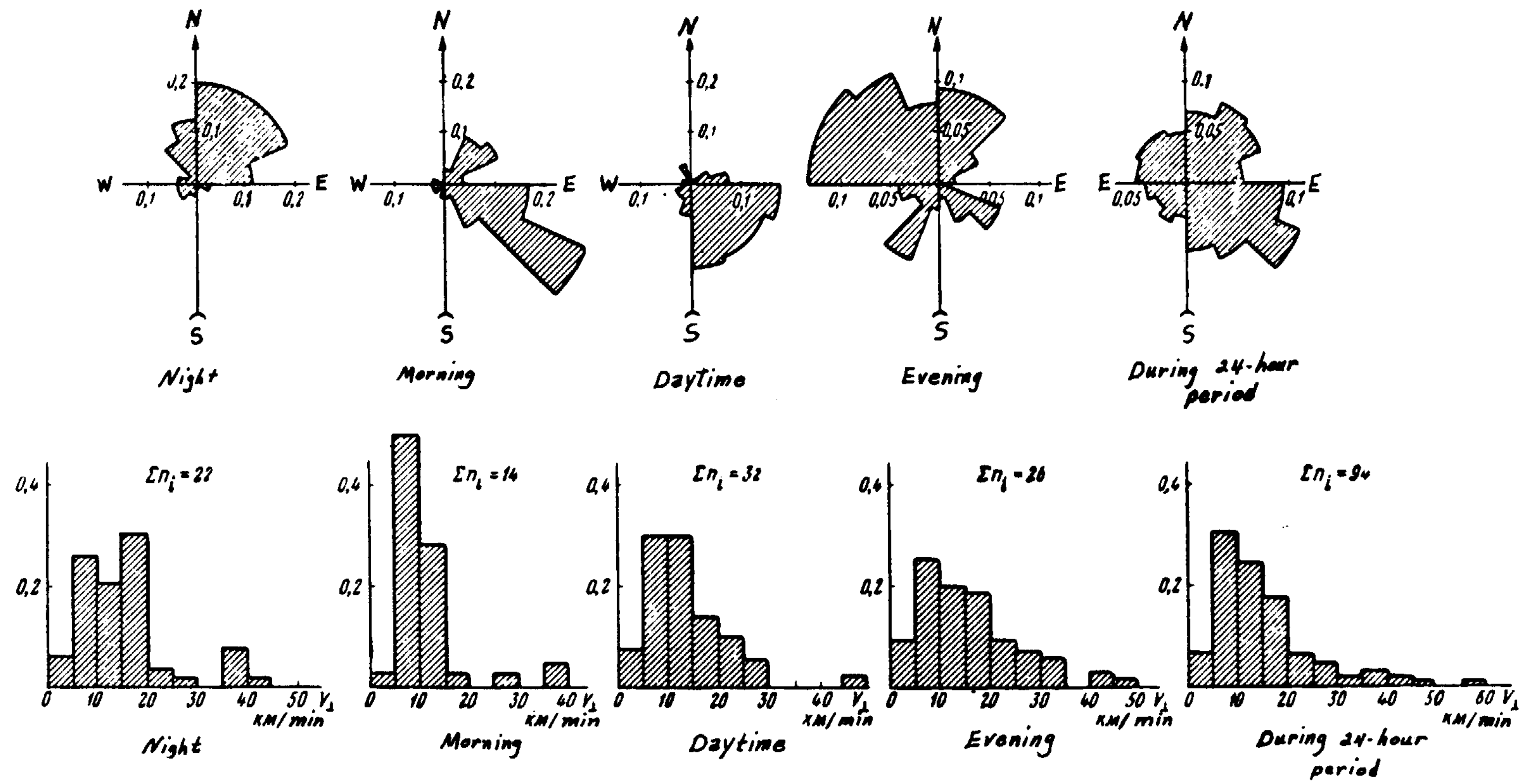

Figure 11.- Histograms of the magnitude $V\perp$ and of the direction (angle $\beta\perp$) of drift velocity, obtained without taking anisotropy into account, i.e., histograms of apparent velocities; F-2 layer. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axes and radii.

DRIFT OF SMALL-SCALE IRREGULARITIES IN THE F-2 LAYER

Yu. V. Kushnerevskiy and Ye. S. Zayarnaya

Abstract

Determination of the magnitude and direction of the velocity for small-scale irregularities in the F-2 layer has been made.

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The results of observations for the period of 1956-1958 show drifts of the irregularities in the F-2 layer in western and eastern directions. The average velocity of the movement of irregularities is about 80 m/sec.

The comparison of the average results, obtained at different stations in the USSR, show large scale circulations in the ionosphere or large scale travelling disturbances. There are cases of double distribution curves of amplitude and also of the periodic amplitude oscillations.

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Since 1956, observations of the movement of small-scale irregularities in the region of the F-2 layer have been conducted at the Research Institute for Terrestrial Magnetism and Radio Wave Propagation of the USSR Academy of Sciences (IZMIRAN). Since July 1957, these observations have been conducted in accordance with the IGY program, which was supplemented by an observation program especially designed for Soviet stations (1). The adoption of a supplementary program was prompted by the necessity of obtaining a sufficiently large amount of statistical data which could be processed accordingly. At the same time, consideration was given to the fact that, during days of ionospheric disturbance, when the ionosphere is in a diffused state or exhibits a strong absorption, it is almost impossible to conduct observations of drifts in the ionosphere.

In addition, experience gained during previous investigations has shown that only 20-30% of the total number of recorded observations can be processed by using the similitude method. This is mainly due to the presence of very slow or chaotic (random) variations in the amplitudes of the recorded signals. A single observation session of 5 minutes duration is quite sufficient for achieving a correct statistical processing of the recordings obtained.

Certain data are given below, concerning the equipment used and the results obtained in measuring the drift of small-scale irregularities in the F-2 layer region, recorded at IZMIRAN (Krasnaya Pakhra, North 55° 28', East 37° 19') during the period of January 1956 to December 1958. Some of these data are compared with the results of observations obtained in other Soviet stations.

Equipment

The method used for measuring the movement of small-scale irregularities in the F-2 layer is based on a study of the behavior of individual signals reflected by the ionosphere and recorded at 3 scattered points on the surface of the earth.

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The equipment used for studying the movement of small-scale irregularities consists of a manually controlled ionospheric station (2). A frequency range of 1.0-16.0 mc (megacycles) is used. The radiation power is of the order of 5 kw per pulse. The pulse length is of the order of 200 mksec (microseconds). In order to protect the measurements from the effect of polarization fading, radiation is effected by means of two mutually perpendicular rhombic antennas, which in 1958 were replaced by "delta"-type antennas. The presence of polarization transmitting antennas allows the radiation of linearly polarized or circular polarized oscillations, i.e., the radiation of right-or left-polarized waves. The receiving antenna-dipoles are installed at the vertex points of a right triangle, the legs of which measure 160 and 190 m respectively. The arrangement of the antennas is shown in Figure 1.

The receiving antennas are connected to the inlet of an electronic antenna switch by means of a high-frequency coaxial cable. By means of the switch, the antennas are alternately connected to the input of the same receiver. The commutation frequency is equal to 50 cycles. A standard superheterodyne receiver with a transmission band of about 18 kc (kilocycles) is used. From the output of the receiver, the signals received are fed to a visual control oscillograph. The signals necessary for recording purposes are separated with the aid of gate devices. Following detection (or rectification), the separated signals are then converted into pulses with a duration of about 1/100 sec, and are fed simultaneously to both pairs of vertical deflecting plates in a two-beam electron tube. The electron beam tube has no time base, and therefore its screen only shows points corresponding to the bases and peaks of the recorded signals fed by various receiving antennas. The separation of signals is accomplished by brightning the tube with pulses controlling the antenna switch. When the first antenna is connected to the receiver, a bright-up pulse is fed at the same time to the first beam of the tube. When the second antenna is hooked up, the first beam of the tube undergoes a less intense brightning. Thus, the signals from the first and second antennas differ from each other in their brightness of bias lighting. When the third antenna is hooked up, the second beam of the tube is brightened at the same time. The time variations of the amplitudes of the separated signals are recorded on a 35-mm movie film from the screen of a two-beam oscillograph. Time marks are traced on the recording every 2 seconds. The travelling speed of the film is equal to 17 cm/min. A sample of a recording is illustrated in Figure 2. The top section of this figure shows 2 curves, which correspond to variations in the amplitudes of signals fed by the first and second antennas. The lighter (brighter) curve corresponds to the signal transmitted by the first antenna. The bottom curve corresponds to the signal transmitted by the third antenna. Time marks are visible in the form bright dots or breaks in the recording lines. The film was travelling from right to left.

Drift in the F-2 Layer Region

The velocities and directions of movement of small-scale irregularities in the F-2 layer were derived by computation from average time shifts. The latter were found from the magnitude of displacement of similar amplitude fading sectors of signals recorded at 3 scattered points (2,3). Shifts were generally determined by the visual method, and a correlation analysis of recordings was performed only in isolated cases. Recordings which had no similar sectors were not processed.

Table 1 lists the most probable velocity values and the predominant directions of drifts in the F-2 layer at various times of the day during the 1956-1958 period.

TABLE 1

	Night		Morning		Daytime		Evening	
Year	m/sec	Degrees	m/sec	Degrees	m/sec	Degrees	m/sec	Degrees
1956	80	100 280	60-80	270*	40-60	100 280	60-80	280*
1957	100	280	60	280*	60-80	280	80	110* 280
1958	60	280	60-80	220* 280	40-60	110 280	40-60	100* 280

* A considerable scattering (spread) of the directions of movement is observed.

In case two almost equal predominant directions of the drift are observed, both of these directions are listed in the table. The angles determining the direction of movement are measured clockwise from the direction towards the North. Histograms showing the velocities and directions of movement of irregularities at various times of the day during the observation period of July 1957 to July 1958 are shown in Figure 3. The 24-hour day is divided into the following periods: night - from 22.00 to 06.00 hours; morning - from 06.00 to 10.00 hours; daytime - from 10.00 to 18.00 hours; and evening - from 18.00 to 22.00 hours. In histograms showing the direction of movement, the number of cases having a prescribed direction are plotted along the radius.

From Table 1 and Figure 2, it can be seen that a considerable scattering in the directions of drift takes place during the morning and evening hours. A predominant direction of movement towards the West (280°) is observed during the entire 24-hour period. A movement towards the West is observed in the evening and at night, while an Easterly direction of movement also makes its appearance in the morning and during the day. An Easterly direction of movement during night and evening hours is not so sharply expressed.

The drift velocity increases during the transition from daytime to night time. A considerable spread of drift velocities (20-300 m/sec) is observed during the entire 24-hour period. However, the velocities lie in the range of 20-120 m/sec during daytime. The higher apparent drift velocities during night hours are apparently connected with the presence of considerable turbulent processes in the ionosphere, which also affect the spread of movement directions observed during morning and evening hours. It should be noted that, in accordance with the methods used (2), the apparent drift velocities were determined (these velocities will be further designated simply as the drift velocity). At the same time, it is necessary to consider the fact that the velocity and direction of movement of small-scale irregularities were mostly measured during daytime, since at night there is usually a considerable amount of diffusivity and a high level of external interferences, which sometimes make it impossible to conduct observations. It should be noted that very low velocities, of the order of 20 m/sec, were sometimes observed during daytime and evening hours.

Table 2 lists the most probable values of velocities and of predominant directions of movement for various seasons of the year, which were obtained during the period of observation from 1956 to 1958. Histograms of velocities and directions of movement, plotted for various seasons of the year and covering the period of observation from December 1957 to November 1958, are shown in Figure 4.

TABLE 2

Year	Winter		Spring		Summer		Fall	
	V, m/sec	Φ degrees	V, m/sec	Φ degrees	V, m/sec	Φ degrees	V, m/sec	Φ degrees
1956	70	290	60-80	100* 280	60-80	290	60-80	100* 300
1957	40-80	100 280	40-80	270*	40-80	120 290	80-100	280
1958	40-100	100 220 280	60	100* 280	60-80	280	60-80	100*

* A considerable spread in the directions of movement is observed.

It can be seen that the drift velocities of small-scale irregularities in the F-2 layer vary from 20 to 280 m/sec, although the most probable values of velocities lie in the range of 40-100 m/sec. In the summer and winter of 1958, the movement velocities lie mostly in the range of 40-120 m/sec, while the most probable values in the spring and fall lie in the range of 20-80 m/sec. In addition, it can be seen that higher velocities, amounting to as much as 280 m/sec, were observed in the fall and winter.

The distribution of the directions of movement, according to the season, exhibits a considerable amount of spread. The following predominant directions were established: in winter - 100° and 280°, in spring - 100° and 280°, in summer - 280°, and in the fall - 100°, and less frequently 280°. Figure 4 shows that, in 1958, another direction of movement was observed in winter, namely a direction towards the South-West, while predominant directions towards the West (280°) and the East (100°) were observed in summer and in the fall respectively.

On the basis of the figures listed in Table 3, it is possible to compare the results of observations of the movement of small-scale irregularities in the F-2 layer, conducted at various Soviet stations during the period of July 1957 to July 1958.

Table 3 lists the most probable values of drift velocities and the predominant directions of movement. It can be seen that the most probable drift velocities lie in the range of 40-120 m/sec. It is

possible to assume that the predominant velocity in the F-2 layer is
equal, on an average, to about 80 m/sec. The directions of movement
vary greatly. In all Soviet stations, a direction of movement is ob-
served, which is predominantly oriented towards the West (240-280°)
and the East, with a small deviation towards the South (90-150°). A
significant deviation towards the South is only observed at the Tomsk
station. On the basis of statistical data, it is possible to assume,
apparently, that a general circulation of air masses takes place in
the ionosphere, or that it contains moving disturbances (perturbations)
extending over large areas of the globe. A comparison of data on the
drift of irregularities in the F-2 layer, occuring at the same time,
shows that the magnitudes of the velocity and direction of movement F
frequently vary at various stations in the Soviet Union. Consequently, 2
the movement of small-scale irregularities in the F-2 layer has a 0
local character.

TABLE 3*

Month, Year	Moscow		Gor'kiy		Khar'kov	
	V, m/sec	Φ degree	V, m/sec	Φ degree	V, m/sec	Φ degree
July 1957	70	280	--**	--		
August 1957	80	120	60-80	260	60	240
September 1957	90	270	60; 160	260	80	240; 270
October 1957	--	--	50; 90	260	40	240
November 1957	80	210; 270	80-120	290	40-70	240
December 1957	60-100	110; 210	60-80	260	40	200
January 1958	60	110	80-100	260	100	50
February 1958	60	240	80-120	270	140	--
March 1958	60	100; 280	40-80	260	80	170; 250
April 1958	40	280	--	250	--	210
May 1958	60	280	40-70	260	--	--
June 1958	70	280	40-60	260	80; 120	180; 270
July 1958	70; 90	280	40-60	280	--	--

* The data used for comparing the results of observations of drifts of small-scale irregularities in the F-2 layer, conducted at Soviet stations, were obtained from the B-2 (or V-2 : Russian transliteration?) Information Storage World Center.

** A dash indicates that it was not possible to obtain a predominant (or preferential) value for the velocity or direction of the drift.

Table 3 - Concluded

Month, Year	Tomsk		Simeiz		Ashkhabad	
	V, m/sec	Φ degree	V, m/sec	Φ degree	V, m/sec	Φ, degree
July 1957						
August 1957						
September 1957	60-80	330				
October 1957	40-60	240				
November 1957	40; 80	60; 330				
December 1957	80	240	--	--		
January 1958	40-70	240	40-60	230	70	240
February 1958	60	240	80-100	270	80	230
March 1958	60-80	240	60-80	130; 230	60	220
April 1958	60	240	80	270	60-80	270
May 1958	60-80	240	100	60; 270	60	120; 240;
June 1958	100	270	80-100	240	50	90; 270
July 1958	60 80	240	100-120	30; 270	40-70	270

Distribution of Amplitudes and Periodic Oscillations

Studies of the statistical properties of the irregular structure of the ionosphere are based on the study of the characteristic behavior of an individual signal reflected by the ionosphere (4). Consequently, cases of diffuse reflections from the ionosphere are not examined, and only circular-polarization waves are selected for recording purposes. For this reason, the data given in this article refer only to results of observations performed on one of the magneto-ionic components of the signal.

As Ya. L. Al'pert has shown (4, 5), the distribution of the amplitudes of a radio signal reflected by an irregular ionosphere is subject to Raleigh's law. The correctness of this assumption was checked. A total of 74 observations of the variations occuring in the amplitudes of received signals were investigated, based on recordings obtained in May, October and November 1956. It was established that Raleigh's distribution law was only applicable to 48 cases. This constitutes 65% of the total number of observations. Double-humped amplitude distributions were obtained in the remaining 26 cases (Figure 5). Two examples of the amplitude distributions which were obtained are shown in Figure 5. Figures 5a and 5c show amplitude observations occuring at 1-minute intervals during the period of observation. Figures 5b and 5d show amplitude distribution curves for a growing observation range, i.e., each successive curve includes all previous distributions. In general, the distribution is subject to Raleigh's law (Figure 5a and b). At the same time, small deviations from this law are also observed; Figures 5c and 5d show that a double-humped distribution occured during a period of 5 minutes. If the presence of a second maximum (peak) is weakly expressed in the first case, then, in the second example, the second peak is more clearly expressed than the first peak. The appearance of a third peak can be noted in Figure 5c. Such double-humped distributions are most frequently observed during the morning and evening hours, when the ionosphere gradually shifts from a daytime to a night time condition, or vice-versa. During this time, as a rule, the ionosphere becomes more "turbid" (4). In double-humped amplitude curves, the first peak is almost always higher than the second peak. However, in a number of cases (20%), the second peak is higher than the first one. In view of the presence of double-humped amplitude distributions, it is possible to assume that two independent processes, superimposed on each other, may possibly take place in the ionosphere.

Cases are also observed, in which the ratio between the average square amplitude and the square of the average value of the amplitude of the recorded signal is greater than a value of the order of 1.27, which does not agree with the conclusions drawn by Ya. L. Al'pert (4).

Cases of almost sinusoidal oscillations are sometimes observed during the recording of variations in the amplitudes of radio waves reflected by an irregular ionosphere. Such oscillations cannot be caused by the interaction of two magneto-ionic wave components, in view of the fact that polarization fadings were excluded since only one of these components were received. A number of samples of obtained recordings with periodic oscillations are illustrated in Figure 6. Figures 6a and b show cases in which oscillations start at a high frequency ($T \sim 1$ sec), and then the oscillation period gradually increases ($T - 7$ sec). Figures 6c and d illustrate a case, in which periodic oscillations were observed during almost the entire bright (lighted) period of a 24-hour day. Figure 6e shows the recording of periodic oscillations gradually changing into random amplitude variations. Figures 6f, g, h, i and k illustrate various types of periodic oscillations, whereby Figures 6i and k show short-period oscillations superimposed on long-period oscillations. The number of different types of periodic oscillations is not very great, but all of them, as a rule, differ from each other in duration, oscillation period and type of attenuation.

Such periodic oscillations in the amplitude of a reflected signal amount to about 5-10% of the total number of observations, and are recorded most frequently during daytime (66%). During morning and evening hours, such oscillations were less frequently observed, usually at the rate of 18% and 14%, respectively; they are practically never observed at night. Most often, periodic oscillations last for a period of several minutes. Sometimes, however, periodic oscillations are noted during several successive 5-minute observations, conducted at 1-hour intervals. On rare occasions, these oscillations may last almost from sunrise to sunset. Cases are sometimes observed, when periodic amplitude oscillations suddenly set in, and then slowly fade. In such a case, a gradual increase in the oscillation period is always observed.

A preliminary analysis of recordings with periodic amplitude oscillations shows that the oscillation period may vary within a very wide range, approximately from 0.5 to 40 sec and more. The most probable value of the oscillation period is equal to about 5 sec. The existence of periodic oscillations can apparently be explained by the presence in the ionosphere of moving wave-like perturbations (disturbances) of the plasma oscillation type (5).

Conclusions

In the F-2 layer, the predominant direction of movement of small-scale irregularities is towards the West or East, with small deviations towards the North or South. At the same time, a Western direction of movement is observed in the great majority of cases. The velocity of the movement of irregularities varies within a very wide range, from 20 to 300 m/sec. The most frequently observed velocity of movement is approximately equal to 80 m/sec.

Apparently, a general circulation of gases or a displacement of some kind of disturbances, extending over the wide areas of the earth's atmosphere, take place in the ionosphere. Evidence of these facts is the presence of a common direction of movement of irregularities observed in all observation stations, at a constant magnitude of the most probable velocity of movement. However, a comparison of hourly values of movement velocities and directions shows a considerable spread of these values in case of small-scale irregularities in the F-2 layer. Consequently, the movements of these irregularities still have a local character.

The use of the similitude method in spaced-aerial reception does not permit to obtain complete data on the movement of irregular formations in the ionosphere. In order to obtain such data, it is necessary to perform a correlation analysis of the recordings. In view of the presence of complex amplitude distributions and periodic oscillations, it is necessary to work out a new and more detailed approach to the theory of the statistical nature of the irregular structure of the ionosphere.

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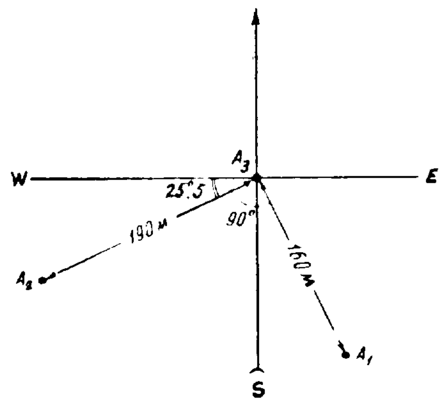

Figure 1.- Location of receiving antennas.

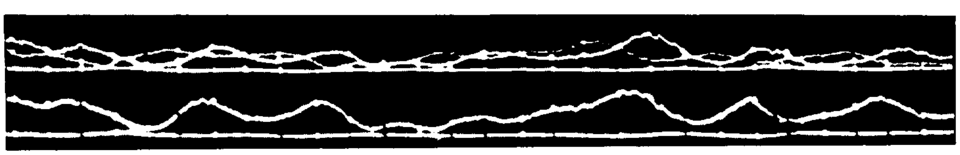

Figure 2.- Sample of recording (13 October 1956; 09.37 hours; F-2 layer; 10.5 megacycles).

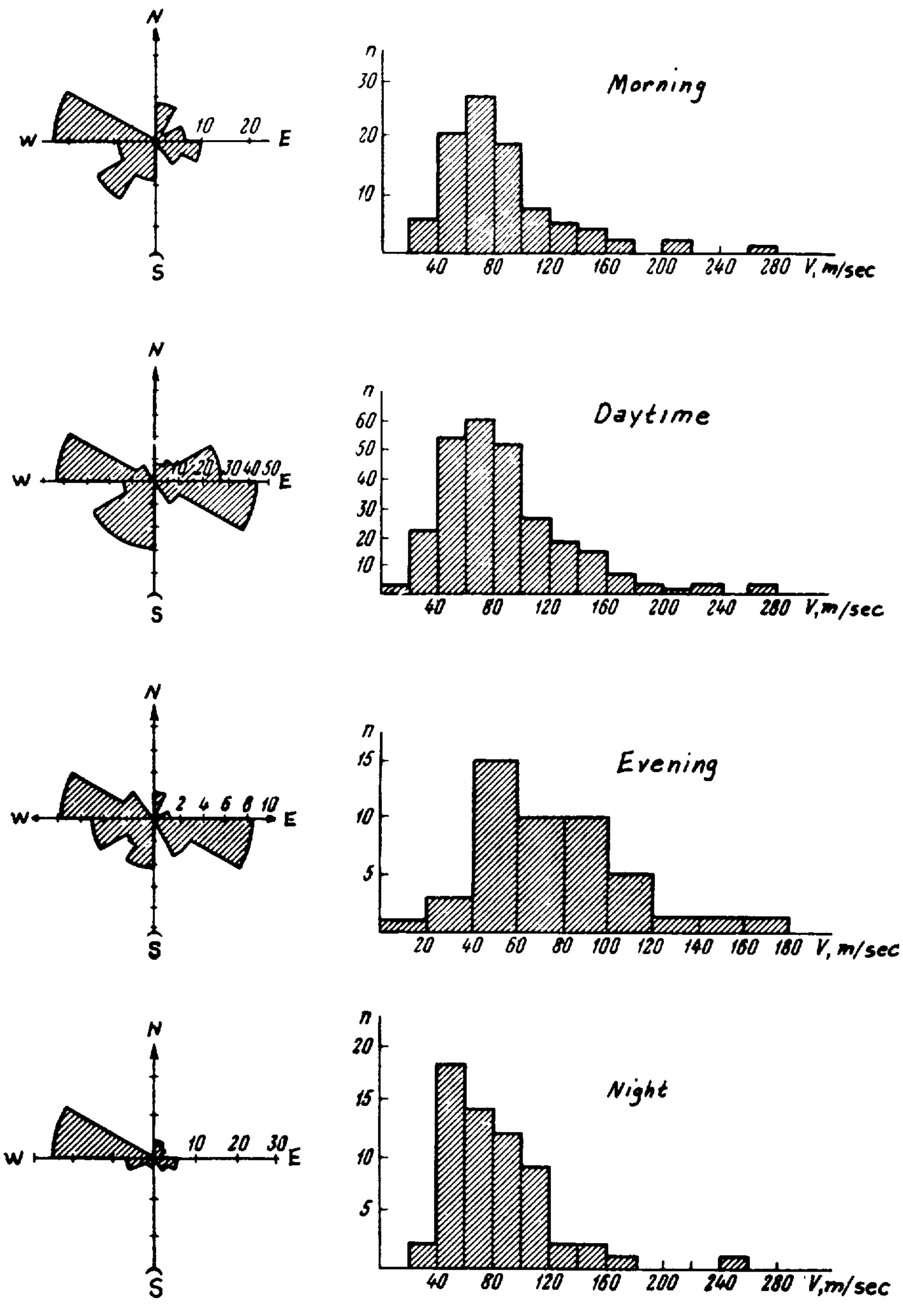

Figure 3.- Histograms showing the magnitude of velocity and direction of movement in the F-2 layer at various times of the day during the period of July 1957 to July 1958; n - number of cases.

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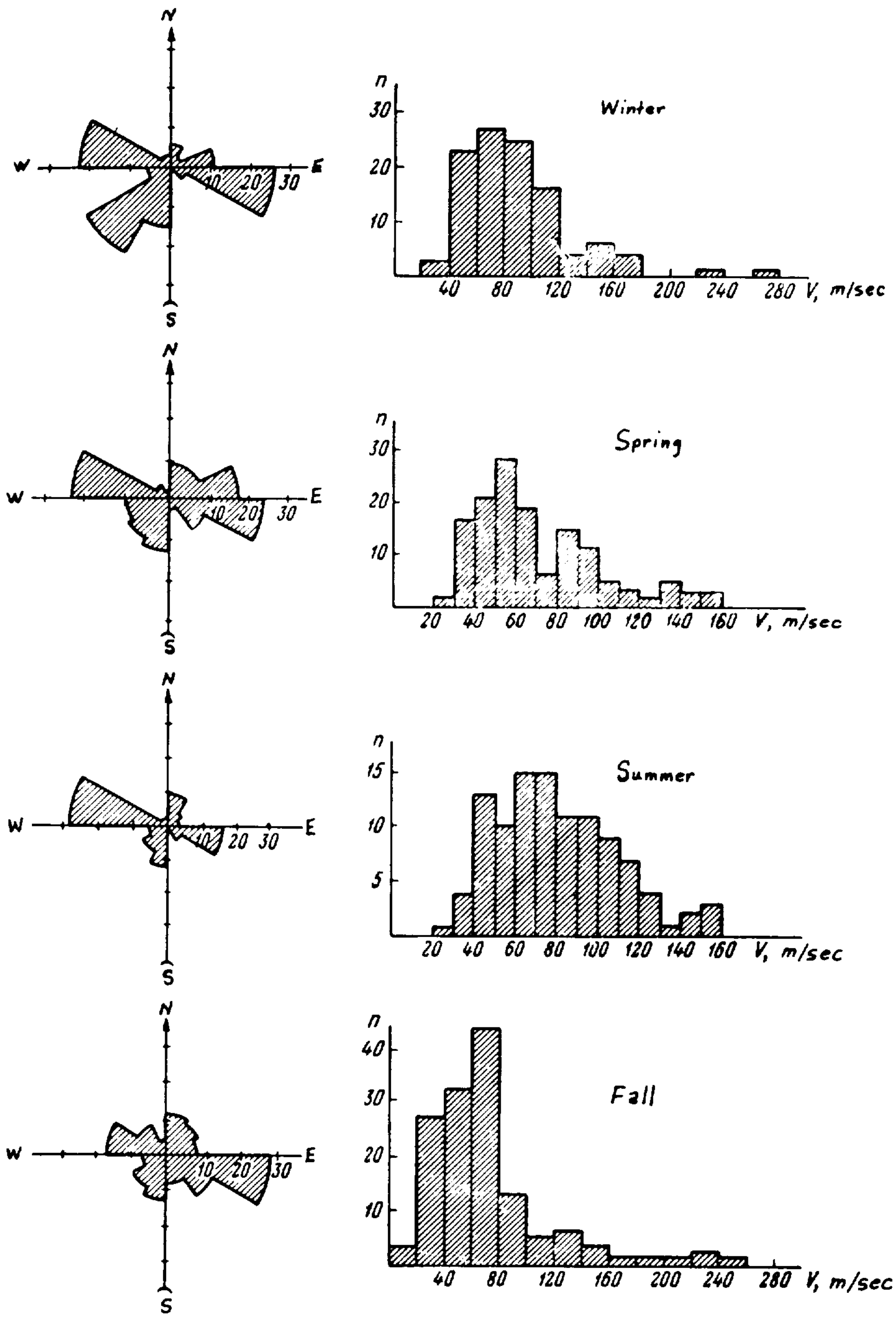

Figure 4.- Histograms showing the magnitude of velocity and direction of movement in the F-2 layer at various times of the year during the period of December 1957 to November 1958; n - number of cases.

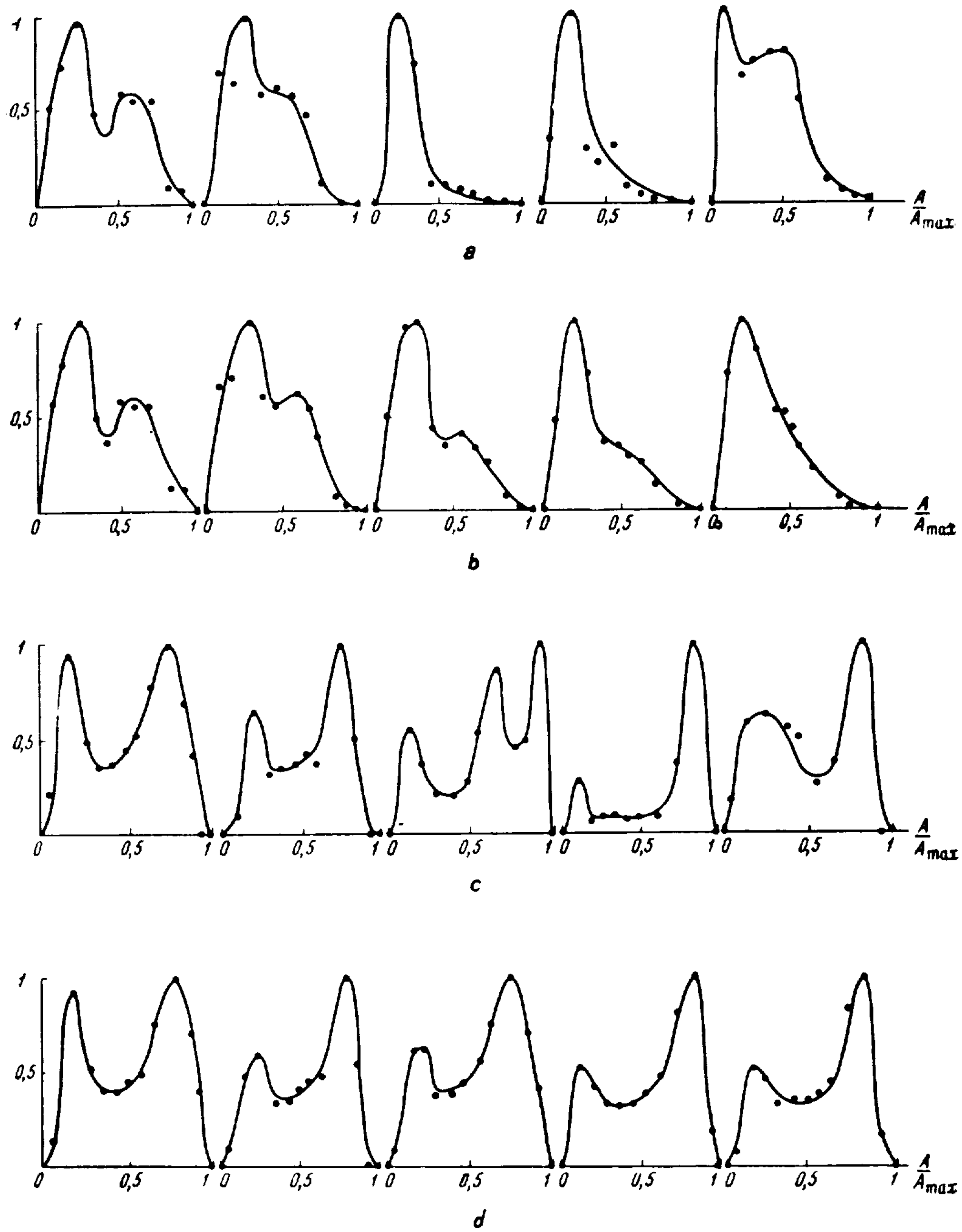

Figure 5.- Amplitude distribution curves. a and c - amplitude distributions obtained during 5 consecutive 1-minute long observation periods; b and d - variation in amplitude distribution as the length of the observation period is increased from 1 to 5 minutes. Cases a and b refer to 30 July 1956, 11.04-11.09 hours; F-2 layer; 6.0 mc (megacycles). Cases c and d refer to 14 October 1956, 11.07-11.12 hours; F-2 layer; 6.74 mc; A A_{max} - relative magnitude of the signal.

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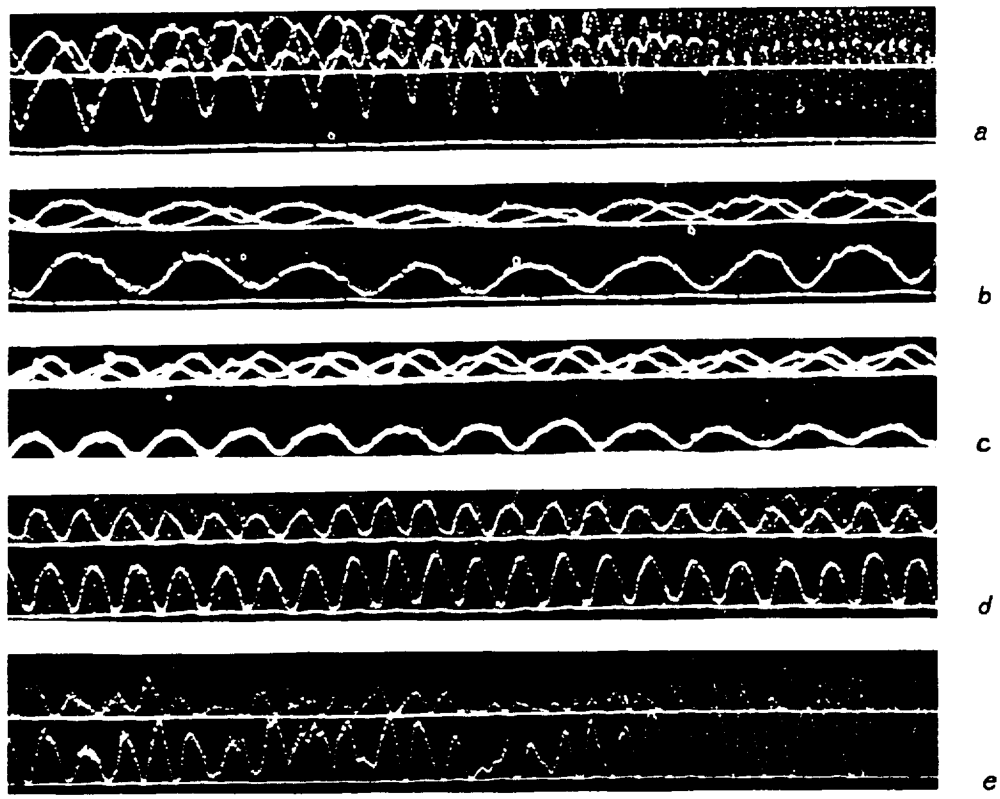


a - 21 November 1957, 15.00 hours; F-2 layer; 9.12 mc.

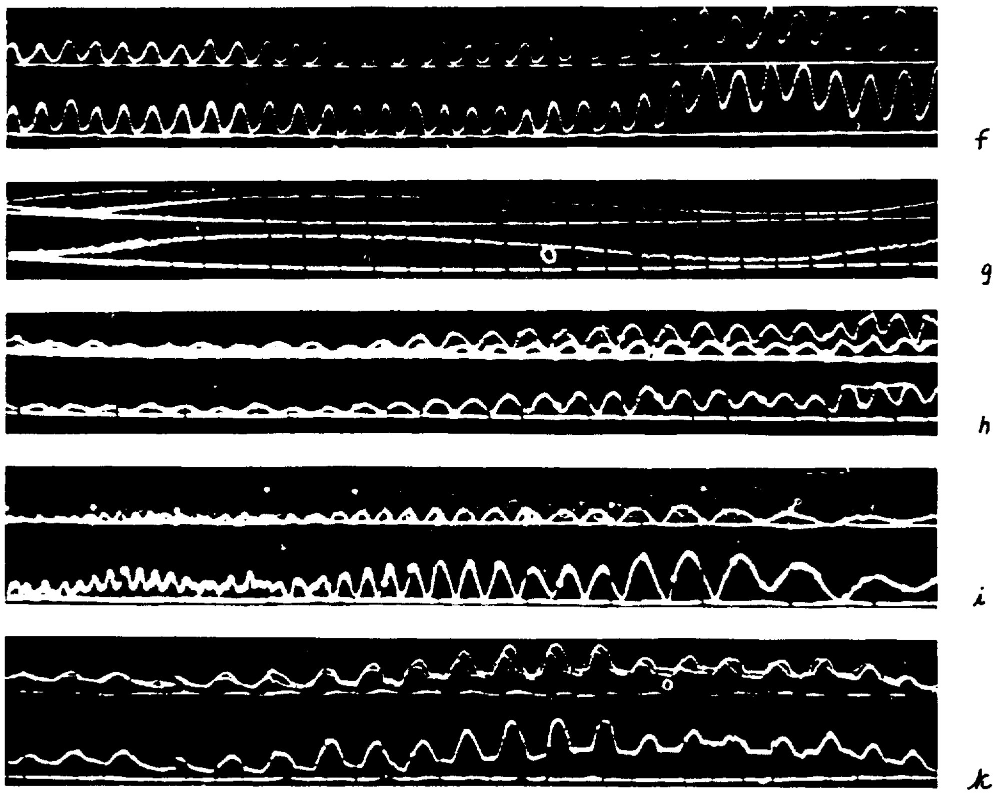
b - 21 November 1957, 08.00 hours.

c - 12 December 1957, 08.00 hours; F-2 layer; 6.3 mc.

d - 12 December 1957, 12.04 hours; F-2 layer; 7.7 mc.

e - 14 December 1957, 13.03 hours; F-2 layer; 11.4 mc.

Figure 6.- Samples of recordings showing the presence of periodic amplitude oscillations in the recorded signals.



f - 16 December 1957, 15.00 hours; F-2 layer; 8.15 mc.

g - 12 September 1957, 08.00 hours; F-2 layer; 6.3 mc.

h - 16 April 1957, 11.35 hours; F-2 layer; 7.2 mc.

i - 11 May 1958, 12.00 hours; F-2 layer; 9.0 mc.

k - 11 May 1958, 15.00 hours; F-2 layer; 9.0 mc.

Figure 6.- Concluded.

F-20

ORIGINAL RESULTS OF RADIOTECHNICAL OBSERVATIONS OF THE MOVEMENT OF IRREGULARITIES IN THE IONOSPHERE (WINDS) OVER ASHKHABAD AT ALTITUDES OF 200-300 KM.

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V. P. Prelygin and V. P. Petinov

Abstract

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The paper describes observations of drift of the ionospheric irregularities in the layer over Ashkhabad ($\varphi = 37^{\circ}\ 55'$; $\lambda = 58^{\circ}\ 18'$) between January 1 and June 30, 1958. The method of spread reception with short base is taken as the basis of observations. Brief characteristics are given of the equipment, methods of measurement, and processing of results. The results of observations are given monthly and for the whole period.

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In accordance with the IGY program, scientific-technical personnel working at the Ionospheric and Wave Laboratory in the Institute of Physics and Geophysics of the Academy of Sciences of the Turkmen SSR have designed a unit for studying the drift of irregularities in the ionosphere and its irregular structure. After an experimental range for conducting radiotechnical investigations was set up (Ashkhabad, North $37^{\circ}\ 55'$, East $58^{\circ}\ 18'$), regular observations were started on 1 January 1958. Observations were based on the use of the spaced-aerial reception method with a small base (1).

Experimental results obtained during the period of 1 January to 30 June 1958 are presented in this article.

Design of the Equipment

The unit consists of a transmitting, receiving and recording device. The transmitting device includes a push-pull pulsed oscillator with self-excitation. Its technical characteristics are as follows: power, approximately 2 kw per pulse; pulse train rate, 50 cycles; duration (period) of square pulse, approximately 150 mksec (microseconds). The oscillator is connected, by means of a 15-meter long feeder (with a wave impedance of 600 ohms), with a broadband delta antenna, loaded with a resistance of 670 ohms.

The receiving device consists of 3 antennas, which are (wide-) band horizontal dipoles (Nadenenko dipoles), the axes of which are oriented in a North-South direction; these antennas are installed at the corners of a right triangle, the sides of which are 100 m long and are oriented in a North-South and East-West direction. The antennas are connected, by means of a PD-16 two-wire cable (with a wave impedance of 200 ohm), to the input of the device, which is an antenna amplifier capable of effecting a switch from a two-wire line to a single-wire line. After going through the antenna amplifier, the signal is fed to an electronic switch, which performs the following two functions: (1) Alternately connects one of the 3 antennas with the receiver; (2) Simultaneously with the switching of antennas, it creates a voltage used in establishing three scanning levels, required by each of the 3 antennas, in the oscillograph tube. The signals from the 3 antennas then travel through a common cathode follower and are fed to the input of a PRV-type receiver, converted for the reception of pulses with a transmission band width $\Delta f = 16$ kc (kilocycles). From the rf amplifier of the receiver, the signal is fed to the input of a EO-7 oscillograph, equipped with a 13LO36 electron-beam tube provided with a white screen, which ensures a low exposure of the picture. The necessary signal which is received is brightened with the aid of gate pulses produced by a gate generator. The amplitudes of the signals transmitted by all 3 antennas are recorded on a continuously moving photo film. The travelling speed of the film (15 cm/min) is controlled by means of time marks. Minute marks are supplied by the contacts of a marine chronometer; in addition, time marks are supplied every 3.4 seconds by a small Warren motor.

Methods of Observation and Processing of Experimental Data

Observations are made of ionospheric movements in the F-region. The frequency is selected according to the altitude and frequency characteristics of the ionospheric station in such a manner as to exclude an interference between magneto-ionic components and avoid selective (deflecting) absorption. The usual component of a pulse reflected by the ionosphere is recorded. Days of observation are established in accordance with instructions on the IGY program (2) and additional recommendations issued to Soviet stations (3). In addition, since March, observations were made every hour on those days in which it is recommended to conduct observations every 3 hours. The duration of a single observation period amounted to 10 minutes during the period of January to April, 5 minutes in May, and 7 minutes in June.

Periodically, once every 10 days, a check was made to see if the channels of the antenna switch gave the same signal amplification. Watches are checked every day, and the correct feeding of time marks is checked prior to each series of measurements.

Observations are processed by visual methods according to (2,3).

Results of Observations

Experimental data covering the period of January to June 1958 have been processed. The drift velocities obtained apply to altitudes of 200-300 km. General characteristics of the data obtained are listed in Table 1.

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TABLE 1

Month	Number of Scheduled Observations	Number of Actual Observations	Rejected for Non-ionospheric Reasons, %	Rejected for Reasons of: Slow Fading	Rejected for Reasons of: Others	Numerical Values Obtained	Yield of Drift Velocity Values, %
January	152	81	46.9	52	6	23	28.4
February	160	121	26.4	70	8	43	35.5
March	480	390	18.7	151	147	92	23.6
April	216	198	8.3	103	59	36	18.2
May	216	202	6.4	113	34	56	27.7
June	408	348	14.7	160	42	146	42.2

Table 1 shows that only 20-30% of observations can be visually processed, while the remaining observations are either subject to slow fading or are rejected for other ionospheric reasons, such as interferences, absorption, diffusivity, etc.

On the basis of the obtained numerical values for the velocity vector, certain general laws (regularities) can be pointed out. The velocity magnitude exhibits a distribution pattern, which is shown in Figure 1. Average and most probable velocity values are listed in Table 2.

TABLE 2

Month	Range of Velocity Variation, m/sec	Arithmetic Mean Value of Velocity, m/sec	Most Probable Value (Mode) of Velocity, m/sec	Remarks
January	20-110	60	65	Groups of 2 maximum values: 20-40; 50-80 are present.
February	0-190	70	65	Two sharp overshoots: 30-50; 80-90 are present.
March	0-290	67	55	Several sharp overshoots.
April	0-130	70	65	Several weakly expressed groupings.
May	10-180	62	55	Strong fall-off on the second half section of the velocity distribution.
June	10-490	72	55	Several sharp overshoots.

The type of velocity distribution of irregularity drifts approximates the Maxwell (velocity) distribution, which is particularly clearly apparent on hand of the data obtained during March and June, when the greatest number of observations were made. The fact that, during all months, except January, the arithmetic mean values of the velocities exceed the most probable magnitudes, also points to this type of distribution. Thus, during the 6-month period, the velocity magnitude varies within a range of 0-490 m/sec; the arithmetic mean value of the velocity is 69 m/sec; the most probable velocity value is 58 m/sec. These figures agree with the results obtained by other authors (4-10). Histograms of drift directions for the corresponding months of 1958 are shown in Figure 2. The characteristic properties of these histograms are listed in Table 3.

TABLE 3

Month	Predominant Direction	Additional Direction	Month	Predominant Direction	Additional Direction
January	South-West	North-East and South-East	April	West and North-West	South-East and North-East
February	South-West	South-West	May	South-West	North-West; East; South-East
March	South-West	East	June	South-West and North-West	East and North-East

A similar distribution of the magnitude and direction of velocity for a different time of observation was obtained in studies (4, 8), although some figures disagree with the results published in (1, 7). In study (10), a South-East direction is noted as the predominant direction. During the period examined here, it is possible to select April 1958 for purposes of comparison, since data obtained at other observation points during this month are available to us.

	Velocity Range, m/sec	Predominant Direction
Moscow (IZMIRAN)	20-140	North-West
Tomsk *	40-260	South-West

As can be seen, these figures are of the same order of magnitude as those obtained at Ashkhabad **

* - Tabulated figures are used.

** - The values expressing the magnitude and velocity direction of drifts of small-scale irregularities, averaged over a period of several months, which are listed for various points in the USSR in study (10), give results which agree well with a predominant East-West drift direction. (Editor's Note.)

The daily course of the velocity vector components is weakly expressed, although a 24-hour period appears to predominate. This is also confirmed by graphs which we have plotted, showing variations in the mean values of the velocity vector depending upon the time of the day. It does not appear possible to perform a harmonic analysis based on the monthly data obtained. We did not perform a differentiation of altitude distribution, although such an operation would, apparently, allow to make a number of serious corrections prior to arriving at a final conclusion.

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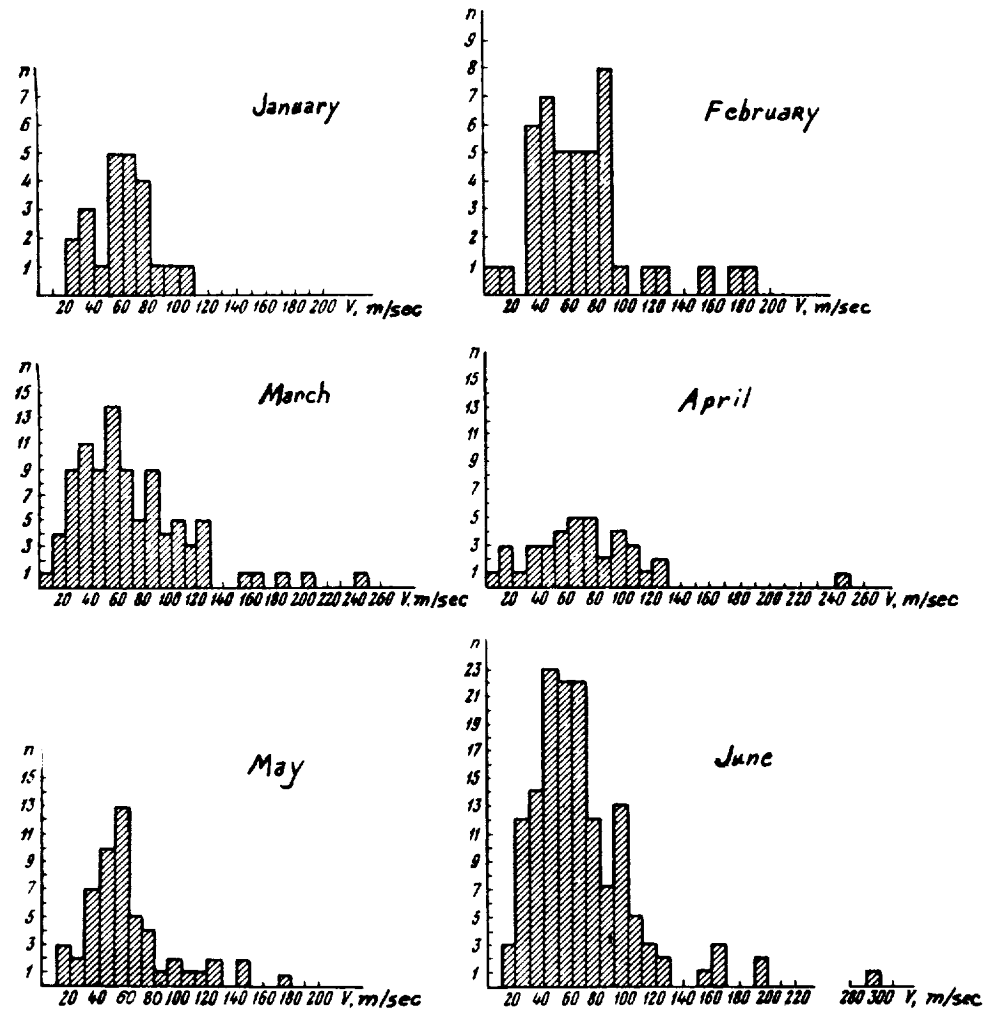

Figure 1.- Histograms of monthly velocity distributions for the Ashkhabad observation station during the period of January-June 1958. n - number of observations; V - velocity.

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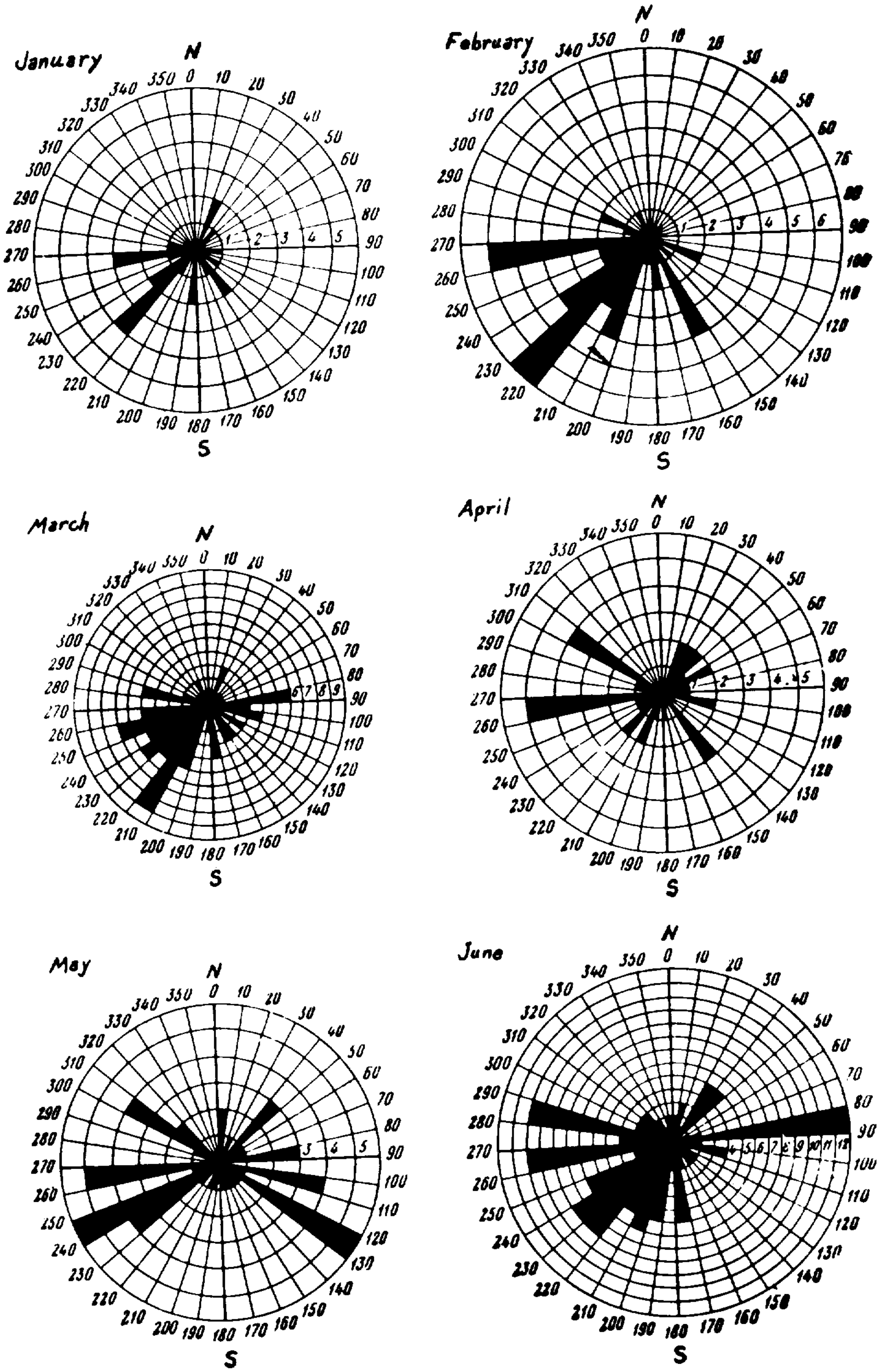

Figure 2.- Monthly histograms showing the directions of drift velocity at the Ashkhabad station during 1958. Degrees are plotted along the limb, and the number of observations are plotted along the radius.

STUDY OF THE IONOSPHERE ABOVE KHAR'KOV DURING THE IGY PERIOD

B. L. Kashcheyev, N. T. Tsymbal, Ye. G. Proshkin

Abstract

The paper summarizes the observations of irregularities in ionosphere, made in Kharkov. It is shown that the reflection of radio F
waves from the F layer of the ionosphere in most cases is specular 2
(coefficient β in 90% is more than 1.0). The angle of scattering of 0
waves from the F layer of the ionosphere varies from 0.3 to 6.0 degrees. The drift velocity of the ionospheric irregularities varies from 10 to 200 m/sec. Some prevailing directions of drift are obtained.

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The fading of a single wave reflected by the ionosphere and fluctuations in the wave travelling direction indicate that the ionosphere is an irregular (non-uniform) medium. The observed picture of field fading may be caused either by a regular drift of the reflecting area, or by a chaotic (random) movement of irregularities. It has been established (1-3) that both types of movements of irregularities occur in the ionosphere. In view of the irregular nature of reflection by the ionosphere, a single wave at the point of reception should not be considered as an individual beam, but as a bundle of scattered waves grouped in a certain direction. The intensity of a signal at any moment is determined both by irregular scattering (diffusion) and "specular" reflection. The ratio of the energies of scattered and specularly reflected waves does not remain constant, but varies during the course of the day.

The "blinking" in the radio emission of radio stars, variations in the angles of arrival of reflected radio waves, fading of an incoming signal, and the propagation of ultra-short waves over ultra-long distances, all result from the irregular structure of the ionosphere.

All these phenomena depend to a considerable extent on the size, volume and electron concentration of irregularities, and also on the character and velocity of their movements. For this reason, a study of the fine structure of the ionosphere is of great theoretical and practical importance.

A study of the ionosphere was initiated in 1954 at the faculty of radio engineering fundamentals of the Khar-kov Polytechnic Institute Imeni V. I. Lenin and is continuing at the present time. By means of a statistical analysis of the amplitudes of signals reflected by the ionosphere, studies are being conducted on the turbidity rate of the ionosphere, the angle straggling of a beam of scattered radio waves, the mean RMS velocity of random movements of irregularities, and fluctuations of the electron concentration. Horizontal drifts in the ionosphere are studied by the method of spaced-aerial reception with a short base (3). This type of work is being conducted in accordance with the IGY program for the study of drifts in the ionosphere (12).

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Equipment and Measuring Methods

Studies of the irregular structure of the ionosphere are being conducted at 2 points: in the city of Khar-kov, and at the Savinsk field laboratory, located 80 km south-east of Khar'kov (North 49° 26', East 36° 55').

The ionospheric station located in the city of Khar'kov has the following characteristics:

1. Pulse power of the transmitter: 30 kw.

2. Pulse time: 100 mksec (microseconds).

3. Pulse repetition rate: 50 cycles.

4. Transmitter band: 2-17 mc (megacycles).

The block diagram of this station is shown in Figure 1. A 20-m high delta antenna is used as an emitter. The unit has 3 receiving antennas installed at the vertex points of a right triangle with a 80-m base. The sides of this triangle are oriented in a South-North and East-West direction.

The superheterodyne receiver has an amplification of 10^6 and a transmission band width of 17 kc (kilocycles). Its amplitude characteristic is linear up to 80 v at the output. The receiving antennas are alternately connected with the input of the receiver by means of an electronic switch. The receiver output is connected to an electron-beam oscillograph in the photo unit, and the pulse is recorded on the screen of the oscillograph in the form of a bright horizontal line. The position of the spot on the oscillograph screen shifts into one of three positions, corresponding to the connected antenna. As a result, 3 horizontal lines are formed on the oscillograph screen, and the length of each line is proportional to the amplitude of the reflected pulse received by the corresponding antenna. These lines are photographed on a 35-mm film moving at a speed of 15 cm/min. Provisions are made for varying the travel speed of the film within a wide range.

At the Savinsk field laboratory, the study of horizontal movements in the ionosphere is conducted in a semi-automatic station having a frequency band of 1.5-15 mc, a pulse power of 10 kw, a pulse time of 100 mksec (microseconds), and a pulse repetition rate of 50 cycles. The transmitter operates with a delta antenna (h = 30 m). In studying the E layer, loops are used as receiving antennas, while dipoles are used in studying the F-2 layer; both loops and dipoles are installed at the vertex points of a right triangle with a 100 m-long base. A vertical sounding (probing) of the ionosphere is performed. The observation of drifts in the ionosphere is conducted on a gyromagnetic frequency, or on a closely related frequency.

When studying the irregular structure of the F layer in the ionosphere, a time selection is used on frequencies above the gyromagnetic frequency, in order to separate the magneto-ionic components of the reflected signal.

The duration of a measuring period is equal to 7-10 minutes in all cases.

The velocity and direction of horizontal drifts in the ionosphere were derived from the recordings of fadings, observed at 3 scattered points, and from the magnitudes of time shifts and spacing geometry, i.e., with the aid of the so-called method of similar fadings (3). For control purposes, approximately 30 observation periods were processed by the full correlation analysis method (10). Results of the correlation processing are listed in (11).

Recordings obtained during reflection from a quiet and undisturbed ionosphere were used for processing purposes.

In addition to the study of drifts in the ionosphere, a great deal of attention was given to the study of parameters describing the statistical properties of the ionosphere. Such parameters include factor β (1,5), fluctuations in electronic concentration δN (6), velocities of random movements V_0 (1), and the angular spectrum of scattered waves θ_0.

As was shown in (1), each single signal reflected from the ionosphere is a superposition consisting of a regularly reflected wave, having a constant amplitude and phase, and a group of scattered waves with random amplitudes and phases.

In this case, the field strength can be represented by the following expression:

$$E = E_o \cdot \cos (w_o t - \varphi_o) + \sum_s E_s \cos (w_s t - \varphi_s). \qquad (1)$$

A check of the accuracy of such an assumption consists in comparing experimental amplitude distribution curves with the corresponding theoretical curves. In case these curves coincide (overlap), it is possible to assert that the above assumption is correct.

As we have shown earlier (4), a probability grid can be conveniently used to check the accuracy of the assumption concerning the composition of a reflected signal (1), on which all calculations are based.

The turbidity rate $\beta^2 = \dfrac{E_o^2}{\sum E_s^2}$, which is the ratio between the energy of a specularly reflected wave and the energy of scattered waves, is determined from the curve $\beta = f \dfrac{\overline{R^2}}{\overline{R}^2}$, obtained in study (5).

The angle straggling of a beam of scattered waves is obtained from the expression (5):

$$\theta_o = \frac{\lambda \, |\overline{\Delta R}|_d}{4\sqrt{4-\pi}\ \overline{R}}, \qquad (2)$$

where λ is the length of the operating wave in meters; $|\overline{\Delta R}|_d$ is the mean value of the absolute difference between the amplitudes of signals received by 2 antennas located at a distance d from each other; $\overline{R}$ is the mean value of the amplitude.

Formula (2) can be used only in case the space correlation factor of amplitudes, received by two spaced antennas, is close to unity. The space correlation factor $\rho_R(d)$ was derived by calculation from experimental data, obtained from two spaced antennas, according to the formula:

$$\rho_R(d) = 1 - \frac{\pi^2 \, \overline{(|R(x) - R(x+d)|)^2}}{4(4-\pi)\,\overline{R}^2}$$

In the present measurements, 3 spaced antennas represented two pairs of antennas oriented in a North-South and East-West direction.

The data obtained from each pair of antennas served as a basis for calculating the correlation factor ρ_R (d) and the ratio $\frac{\overline{|\Delta R|}}{\overline{R}}$, which made it possible to determine the magnitude of angular scattering with the aid of formula (2), if the correlation factor was close to unity.

The magnitude of the mean RMS velocity of random movements of irregularities was calculated according to the formula given in (1):

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$$V_o = \frac{\lambda \overline{R} \, \overline{|\Delta R|}_\tau}{2\pi\tau \sum E_s^2 \sqrt{2} \cdot \sqrt{1+\beta^2}} \qquad (3)$$

where $\overline{|\Delta R|}_\tau$ - is the mean value of the difference modulus of consecutive amplitude values, measured at the time t and the immediately following time $(t + \tau)$.

As Ya. L. Al'pert has shown (6), if the turbidity rate β^2 of the ionosphere is known and altitude-frequency characteristics are available, it is possible to determine the electron density fluctuation:

$$\delta N = \frac{4e\lambda_c^4}{\pi \cdot \sqrt{\pi} \cdot \xi_o z_m \lambda^2 \left(\frac{z_o}{z_m} + 1 - \sqrt{1 - \left(\frac{\lambda_c}{\lambda} \right)^2} \right) \beta^2 M} . \qquad (4)$$

where z_o is the altitude of the ionized layer base; z_m is the half-thickness of the layer; ξ_o is the size of small-scale irregularities. The expression for M is given in (6).

As a result of numerous measurements (7), it was established that the size of small-scale irregularities varies within the range of 75-400 m, whereby most frequently ξ_o = 200 m for the F layer of the ionosphere. This value was used in calculating δN.

Results of Measurements

A. Turbidity Rate β of the Ionosphere

The turbidity rate of the F layer in the ionosphere has been studied since 1954 up to the present time, while a study of the turbidity rate of the E layer has been in progress since August 1957. It was established that, during a period of 24 hours, β assumes values ranging from 0 to 11.5, i.e., the ratio between the energy of a specularly reflected wave and the energy of scattered waves varies within a range of 0 to 132. There is no relation between the turbidity rate β and the altitude of the sun. A very insignificant reduction in the values of β is observed at noon, and a slight increase in β (in comparison with the average value of β) is observed around 16-17 hours local time. A substantial difference in β values during night and day hours was established. A curve showing the distribution of β values during daytime, plotted from the results of measurements performed between September 1957 and January 1958, is illustrated in Figure 2. The distribution of β values during night time (September 1957-January 1958) is shown in Figure 3. This figure shows that β values of 0.5-1.5 are most frequently (80%) observed during night time. In 50% of the cases, the energy of a specularly reflected wave is smaller than the energy of scattered waves ($\beta < 1$). During daytime, β values of 1-4 are most frequently observed (80%). Both during a period of insignificant solar activity (1954-1955) and during a period of maximum solar activity (1957-1958), the energy of a specularly reflected wave is higher than the energy of scattered waves in 90% of the cases during daytime. During a period of maximum solar activity, β values greater than 5 were observed less frequently than in 1954-1956.

Processing of the measurement results showed that, approximately in 90% of the cases, the distribution of the amplitudes of reflected signals follows a normal or Raleigh distribution law.

In the remaining cases, the amplitude distribution exhibits a double-humped character.

Studies of the E layer, conducted on a gyromagnetic frequency during the winter period of 1957-1958, showed that β values varied within a range of $0 \div 7$. In 75% of the cases, the energy of a specularly reflected wave was higher than the energy of scattered waves ($\beta > 1$).

B. Angular Spectrum θ_o of Waves Scattered by the F Layer

Measurements of θ_o were performed during the period from September 1957 to January 1958. The space correlation factor was determined for each measurement of the angular spectrum θ_o; in case of 200 processed measurements, this factor was of the following magnitude: not less than 0.95 - in 54% of the measurements; from 0.95-0.8 - in 40% of the measurements; and less than 0.8 - in 6% of the measurements.

Measurements in which the correlation factor was found to be lower than 0.8 were not examined. Values of θ_o ranging from 0.3 to 6° were observed during the above period of time. A relation between θ_o and the time of day was established.

Histograms showing the distribution of θ_o values during night time and daytime are presented in Figure 4. At night, θ_o values of 1-3° are observed in 74% of the cases (see Figure 4b). During daytime, θ_o values of 0.3-1 were observed with the same frequency (74%) (see Figure 4a).

A connection was found between the values of β and θ_o. Curves showing the variation in the values of β and θ_o during a 24-hour period are given in Figure 5. As can be seen from this figure, a rather well expressed negative correlation between β and θ_o values can be observed. It was established that the daily course of θ_o values is connected both with a variation in the length of the operating wave, as well as with a change in the ratio $\frac{|\Delta R|}{\bar{R}}$, which reaches a maximum at night and a minimum during daytime.

C. RMS (Root-Mean-Square) Velocity of Random Movements of Irregularities in the F Layer

Measurements of RMS velocities V_o of irregularities have been conducted since 1954 up to the present time. As a result of the processing of experimental data, the following values were obtained: V_o - 0.3-13 m/sec. Most frequently, (in 60% of the cases), the following values are observed : V_o = 0.5-1.5 m/sec.

A curve showing the distribution of V_o values for 1957 is given in Figure 6. No significant changes are observed in the distribution of V_o values in case of various phases of the solar activity cycle.

D. Fluctuations of the Electron Density in the F Layer

The values of fluctuations of electron density were calculated according to formula (4), by using the results obtained in the study of β in the F layer and the altitude-frequency characteristics for the winter period of 1955-1956. The size of the irregularities which was selected was equal to 200 m (7). As a result of calculations, values of δN were obtained, equal to $(0.15\text{-}3.8)\ 10^{-2}$, whereby the most probable values lie in the range of $(0.4\text{-}1.0)\ 10^{-2}$. No noticeable relation between δN and the altitude could be found for the F layer.

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E. Horizontal Drifts in the E and F Layers of the Ionosphere

The results of observations of drifts in the F layer during the period of March-August 1958 indicate the presence of a considerable spread in drift directions. However, a prevailing North-West direction of winds after midnight was established in 40% of the cases, and a North-Eastern direction after noon was established in 45% of the cases. Histograms showing wind directions at various times of the day are given in Figure 7. Drift velocities observed in the F layer amounted to 10-200 m/sec, whereby values of 40-50 m/sec were most frequently observed (Figure 8). Figure 9 shows histograms of drift velocities V during daytime and night time. The figure shows that there is no relation between the V values and the time of the day. Histograms of monthly V values are shown in Figure 10. It should be noted that the V values are somewhat higher during the summer months than during the autumn months. Thus, the most probable values of V during the summer period were equal to 40-50 m/sec, while the most probable values of V during spring amounted to 20-30 m/sec.

As a result of measurements obtained for the E layer between September 1957 and May 1958, it was established that a South-Western direction of drifts was the prevailing direction after midnight, while a North-Eastern and South-Western directions were the prevailing drift directions after noon (Figure 11). At the same time, the values of V lay in the range of 18-170 m/sec, while the most probable values were equal to 40-60 m/sec. A histogram showing the magnitude of drift velocity in the E layer of the ionosphere is given in Figure 12.

Conclusions

1. On the basis of a comparison of numerous experimental data, obtained during a study of the turbidity rate of the F layer in 1954-1956 and 1957-1958, it is possible to assert that, regardless of the phase of the 11-year solar activity cycle, the energy of a specularly reflected

wave is higher than the energy of scattered waves ($\beta > 1$) in 90% of the cases during daytime, in case of a quiet and undisturbed ionosphere. A scattered reflection ($\beta < 1$) is observed in 50% of the cases at night.

2. The angular spectrum of scattered waves (θ_o) depends on the time of the day; lower values $(0.3\text{-}1)^{\circ}$ are observed during daylight periods, and higher values $(1\text{-}3)^{\circ}$ are observed during dark periods of the day. The results of θ_o measurements for the F layer are in agreement with the data obtained by other authors (8,9) with the aid of other methods.

3. The angular spectrum (θ_o) of a beam of waves scattered by the F layer is related to the turbidity rate β in the following manner: higher values of θ_o correspond to lower values of β, and vice-versa.

4. Values of the RMS velocity V_o of movements of irregularities in the F layer lie in the range of 0.3-13 m/sec, the most probable values of V_o being equal to 0.5-1.5 m/sec.

No significant differences in the distribution of V_o during various phases of the 11-year solar activity cycle were observed.

5. In the F and E layers of the ionosphere, the prevailing direction of drift of irregularities is a South-Western direction. An increase in the drift velocity of irregularities is observed with increasing altitudes. The measured values of drift velocity lay in a range of 10-200 m/sec. For the E and F-2 layers, the most probable values of drift velocity are 40-60 m/sec.

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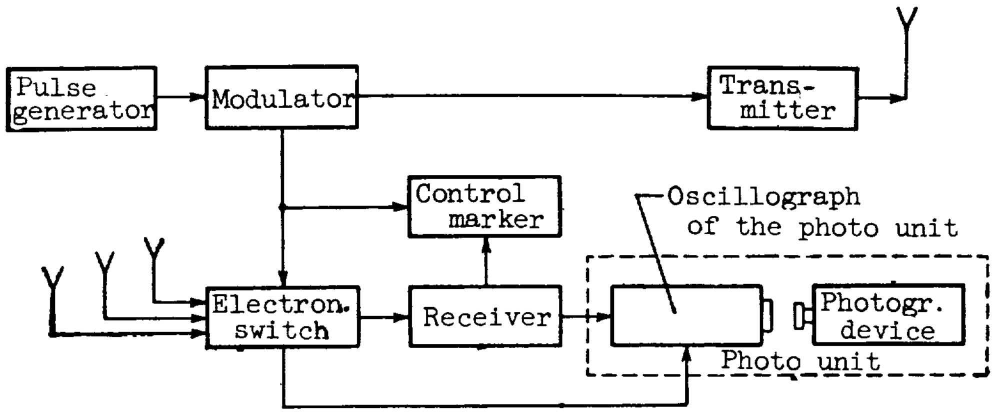

Figure 1.- Block diagram of ionospheric station.

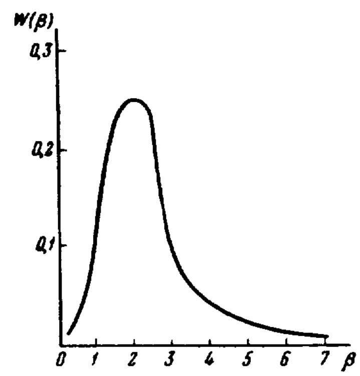

Figure 2.- Curve showing the distribution of β values during daytime (September 1957-January 1958).

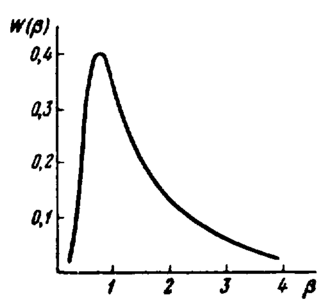

Figure 3.- Curve showing the distribution of β values during nighttime (September 1957-January 1958).

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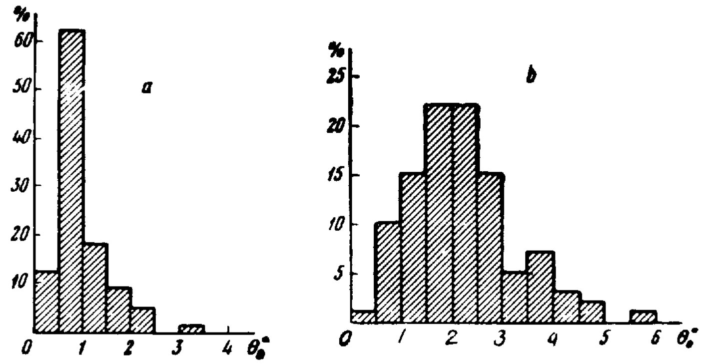

Figure 4.- Histograms showing the distribution of θ_0 values.
a - during daytime; b - during night time.

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Figure 5.- Relation between β and θ_0 values and the time of the day; local statutory time.

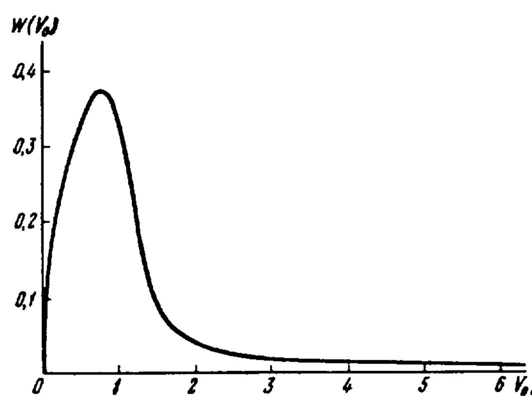

Figure 6.- Curve showing the distribution of V_0 values in 1957.

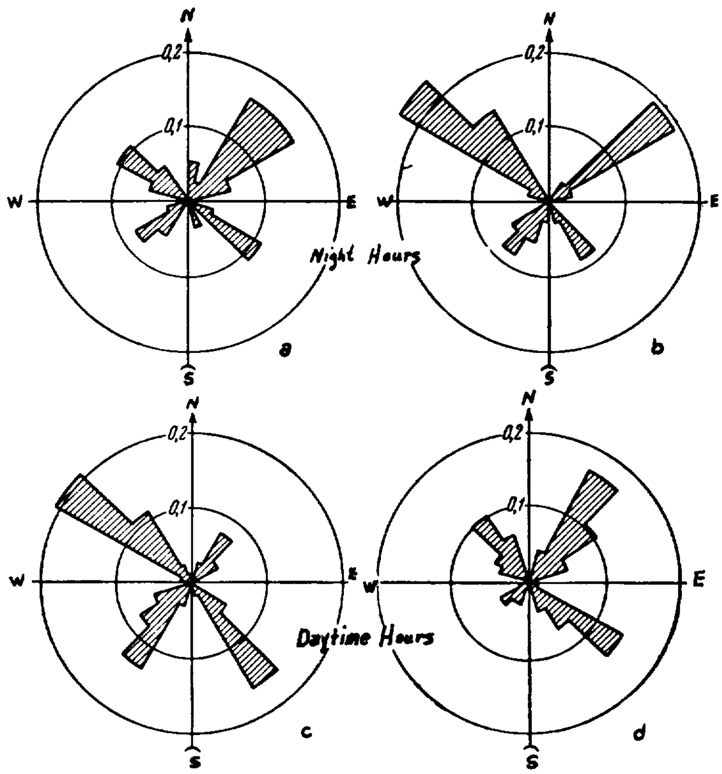

Figure 7.- Histograms of wind directions in the F-2 layer of the ionosphere. a - Night hours up to midnight; b - Night hours after midnight; c - Daytime hours up to noon; d - Daytime hours after noon. The relative number of cases are plotted along the radii.

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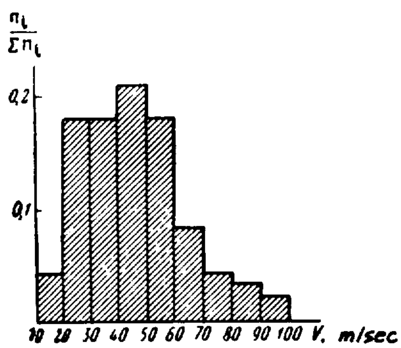

Figure 8.- Histograms of the wind velocity values V for the F-2 layer.

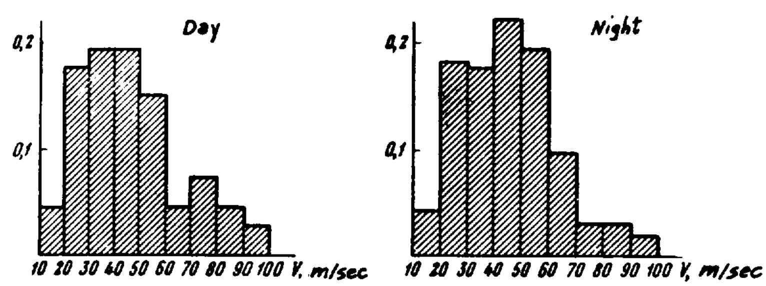

Figure 9.- Histograms of wind velocity values V in the F-2 layer during daytime and night hours. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axis.

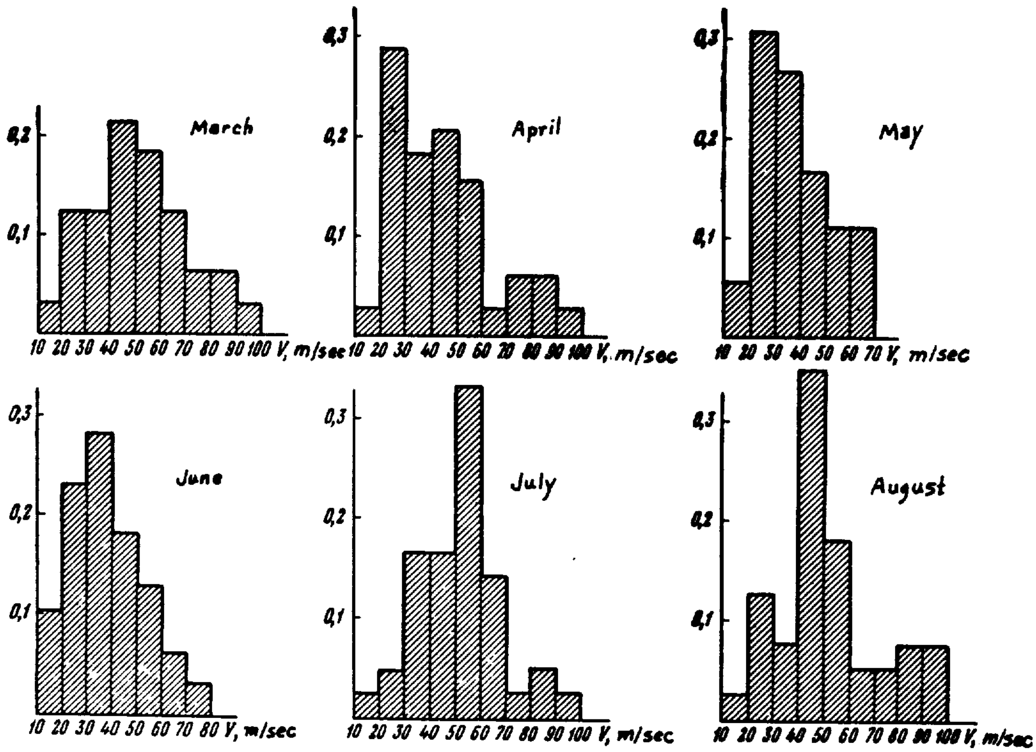

Figure 10.- Histograms showing the distribution of V values during the period March-August 1958. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the ordinate axis.

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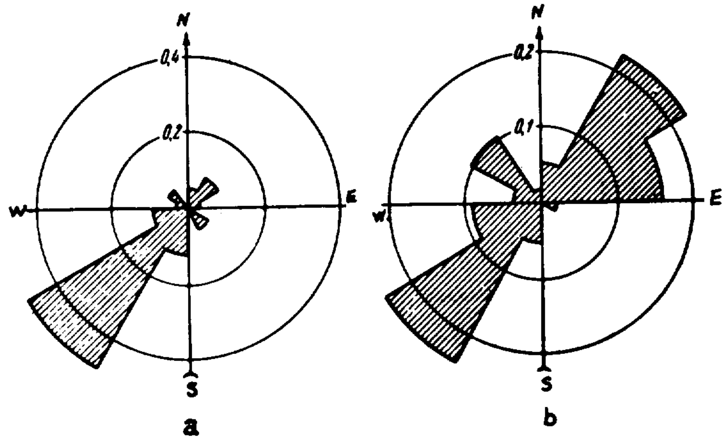

Figure 11.- Histograms of wind velocity directions in the E layer. a - During 00.00-12.00 hours, local time; b - During 12.00-24.00 hours, local time. The relative number of cases $\frac{n_i}{\sum n_i}$ are plotted along the radius.

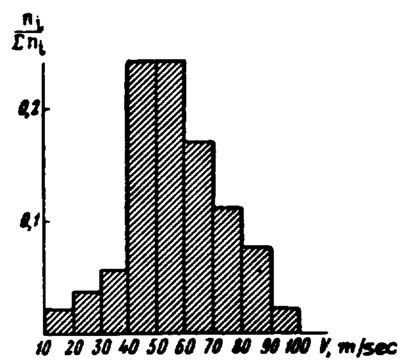

Figure 12.- Histogram of wind velocity values for the E layer.

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DRIFTS OF IRREGULARITIES IN THE IONOSPHERE ACCORDING TO OBSERVATIONS OF THE TOMSK IONOSPHERIC STATION

V. A. Checha, V. Ye. Zelenkov

Abstract

The main characteristics are given of the equipment used for the closely spaced receivers. The results of observations carried out during 8 months are represented for every month by histograms, roses of winds, diurnal and semi-diurnal components of velocity of the solar origin. The influence of lunar tidal oscillations in the E region is noted. The character of the drift of ionospherical irregularities is essentially different for the different heights. Moreover, the positive velocity gradient with the height is observed. The dependence of magnitude of velocity on the magnetical K-figure has been measured. The part of the data, prepared by means of the correlation method, allowed to determine the mean velocity of irregular movements of the inhomogeneities. The increasing of velocity of irregular movements with height is noted. The sizes are measured of the small-scale inhomogeneities, which are usually larger in E region than those in F2 region. A short description is given of the correlator for extraction of the information from experimental data.

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Investigations were conducted with the aid of the short base spaced-aerial reception method (1). In accordance with recommendation (2), a standard equipment set was built. The transmitter operated on a 1.5-10 mc (megacycles) band with a pulse power of about 2 kw. The travelling speed of the photo recorder film was equal to 9.7 cm/min. Observations were performed in case of a clearly expressed magneto-ionic dissociation (splitting), or when the extraordinary (unusual) component was considerably weakened as a result of absorption in the ionosphere. The bulk of the recordings were processed by the similar fading method. The study of drifts in the ionosphere was conducted in accordance with the general IGY program. Observations of the E and F-2 layers, and in part of the F_s layer, were performed. Results of observations conducted during the period of September 1957 to May 1958 (a total of 96 days) are presented in this article.

A total of 1,068 recordings were obtained during this period, of which 406, i.e., approximately 40% of the total number, were used in determining the velocity and direction of winds. A portion of the recordings contained slow and non-characteristic fallings and was not processed. A certain number of recordings exhibited a complete absence of fluctuations. Chaotic (random) fadings were most frequently observed, while periodic or quasi-periodic fadings occurred less frequently. In all cases, when periodic or quasi-periodic fadings were observed, recordings exhibited a great degree of similitude (or similarity). A considerable number of recordings with random-type fadings had a low degree of similitude. Such recordings were not subjected to processing for determining the magnitude and direction of a constant drift, but were utilized in determining the velocity of random movements. Several films containing fadings with a low degree of similitude were processed by the correlation method (3).

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Magnitude of Wind Velocity and Remarks Concerning the Altitudes at Which Movements Could Be Observed

Approximately 1/5 of all recordings suitable for processing purposes refer to the E and E_s layers. The measured velocity values for the E layer lie in the range of 20-260 m/sec. Histograms showing the magnitude of drift velocity in the E layer during each month are given in Figure 1. These histograms show that the most frequently encountered velocity values lie in the range of 60-80 m/sec. The velocity in the F-2 layer varied within a range of 30 to 300 m/sec. From the monthly histograms of wind velocities in the F-2 layer, it is possible to assert that the most probable velocity values lie in a range of 80-120 m/sec (Figure 1b) and that the drift velocity was higher during the autumn and winter months than during the spring months. This characteristic behavior applies both to the E and F-2 layers.

Wind measurements by the spaced-aerial reception method (1) do not provide an immediate answer to the question concerning the localization of movements in the ionosphere. Fadings of a reflected pulse may be caused by the movement of irregularities at any altitude below the reflection level, including this level and up to altitudes at which a noticeable refraction or absorption of radio waves takes place. However, there is an indirect proof of the fact that the altitude of the movements observed is close to the reflection altitude. In study (4), the altitude and motion velocity of individual isolated "clouds" were established at the same time. These moving clouds were located at an altitude of over 100 km, and the distribution of their measured velocities coincided well with the results obtained by the spaced-aerial reception method. The fading of signals from the F-2 layer is caused both by the movement of irregularities in this layer, as well as by movements in the E layer. In some cases, more definite information on the altitude of movements can be obtained. When the critical frequency of reflection from the E layer is close to the operating frequency used during observations of the F-2 layer, then similar values of drift parameters were obtained during successive observations of the E and F-2 layers. In this case, both types of reflection yield results referring to the E layer level. On the other hand, when observations of the F-2 layer were conducted on a frequency considerably higher than the critical frequency of the E layer, the results obtained during successive observation of both layers were different. In this case, the fadings of a signal reflected by the F-2 layer were caused by movements occurring in the F-2 layer itself.

The type of fading exhibited by a reflected signal could be used to estimate the altitudes at which movements take place during successive observation. The E layer usually gave slower fadings, with a high average fading period. The F-2 layer, on the contrary, was characterized by rapid fluctuations with a low fading period, amounting to about 1 second or a fraction of a second.

As a result of observations, it is possible to make the following assumptions concerning the altitudes at which the observed drift takes place:

1. During daytime, when reflection is caused by the E and F-2 layers, whereby the operating frequency is close to the critical frequency of the E layer, the drift parameters should be referred to altitudes of 100-120 km (E layer).

2. At night, during observation of reflection by the E layer or of low-frequency reflections from the F-2 layer, the measured values of wind velocity apparently correspond to movements occuring at the E layer level.

3. In the remaining cases, i.e., during measurement from the F-2 layer on frequencies considerably higher than the critical frequency for the E layer, movements should be referred to the F-2 layer.

Daily (Diurnal) and Seasonal Characteristics of Drifts

As was already noted above, the bulk of the recordings was processed by the similar fading method, which is based on the determination of temporary (or time) shifts. For control purposes, individual recordings were subjected to a correlation processing in accordance with (3), thus allowing the simultaneous determination of the velocity of random movements and of the drift velocity. 24 observation periods (sessions) were subjected to such an analysis. In addition, data for April 1958 were processed by the correlation method with the aid of an analog electronic correlator, which will be described at the end of this article.

Results obtained by the correlation method and by the similar fading method agree fairly well with each other. The directions of drift velocity, obtained by both methods, did not differ by more than 20^{o}. The magnitude of the velocity, determined by a simple method, is usually higher.

For each month (from September 1957 to April 1958), histograms showing the magnitude of drift velocity (Figure 1a and b) were plotted, as well as histograms showing the direction of drift velocities (Figure 2) in the E and F-2 layers. In addition, for each month, graphs were also plotted, which showed the relation between the drift velocity components in a North-South direction (NS-component) and a East-West direction (EW-component), and the time of the day. Such graphs are shown in Figure 3a and b for September-November 1957. During the plotting of histograms and graphs, very high velocity values, corresponding to a period of magnetic storms, were not taken into consideration. As a result of the analysis of the data given in Figures 1, 2 and 3, it is possible to note certain peculiar characteristics of the E and F-2 layers.

In case of the E layer:

1. During the autumn months (September, October, November), the NS-velocity component has a constant component of 30 m/sec, oriented towards the North; the EW component has a constant component of 26 m/sec and is oriented towards the East.

2. During the winter months (December, January, February), a Southern orientation of the NS component and a constant component of about 40 m/sec are characteristic features of the E layer; the constant portion of the EW component continues to be oriented towards the East and is equal to 50 m/sec.

3. During the spring months (March, April, May), the NS component is oriented towards the North and is equal to 30 m/sec; the EW component has rotated towards the West and is equal to 50 m/sec.

In case of the F-2 layer:

1. Autumn months: prevailing direction of the NS component towards the North, value of component, about 50 m/sec; the EW component is oriented towards the West and is equal to 50 m/sec.

2. Winter months: the NS component is oriented towards the South and is equal to about 30 m/sec; the EW component does not exhibit any prevailing direction of orientation.

3. Spring months: in March, during the days of vernal equinox, the constant component of the NS component changed its direction sharply, by turning North and assuming a magnitude of about 30 m/sec; the EW component, as usual, had no prevailing direction.

As noted above, graphs showing variations in the NS and EW drift velocity components as a function of solar time were plotted for constant observations performed over a 24-hour period. A statistical processing and a harmonic analysis of these components permitted to effect a separation of semi-daily and daily variations in their behavior.

In this connection, it was found that the E layer is characterized by the presence of a harmonic of solar origin with a 12-hour period. Harmonics corresponding to lunar tidal fluctuations are also present. Average figures for the NS component of the wind velocity are as follows:

$$V_{NS} = \{59 \cdot \sin (2t + 15^{\circ}) + 19 \cdot \sin (2t' + 10^{\circ}) \quad \text{m/sec.} \tag{1}$$

where t, t' are the so-called solar and lunar time.

For the EW component:

$$V_{EW} = \{44 \cdot \sin (2t - 95^{\circ}) + 24 \cdot \sin (2t' - 115^{\circ}) \quad \text{m/sec.} \tag{2}$$

The periodicity corresponding to tidal lunar fluctuations has not been established for the F-2 layer. In this region, in addition to semi-daily fluctuations, variations of the velocity vector with a 24-hour period are observed. The following expressions for the NS and EW components of the drift velocity in the F-2 layer have been obtained:

$$V_{NS} = \{50 \cdot \sin (2t + 130^{\circ}) + 54 \cdot \sin (t - 45^{\circ}) \quad \text{m/sec} \tag{3}$$

$$V_{EW} = \{61 \cdot \sin (2t - 30^{\circ}) + 63 \cdot \sin (t + 60^{\circ}) \quad \text{m/sec} \tag{4}$$

It should be noted that the measurement of drifts in each successive observation period (session) was performed on the basis of reflections from various levels of the ionospheric layers. At the same time, study (5) has established the presence of a certain phase shift of the V_{NS} and V_{EW} components in relation to altitude. When the expressions (1-4) were obtained, this fact was not taken into consideration.

Winds and Ionospheric Storms

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The character of fadings underwent a sharp change during noticeable magnetic disturbances. This is particularly true in case of the F-2 layer. Very rapid random fadings, characterized by small temporary (or time) shifts, were observed during such periods. A considerable increase in drift velocity was observed to take place during storms. In the E layer, the values of these velocities increased to approximately 260 m/sec. In the F-2 layer, velocities with values of up to 600-1,000 m/sec were observed in case of a Western direction of the drift. It was usually difficult to record fadings during strong magnetic disturbances, since the reflected signal from both layers was very highly blurred and had a low amplitude. Magnetic observations, which have been conducted at the Tomsk ionospheric station since March 1958, permitted to detect a correlation between the wind velocity and the rate of magnetic disturbance. The relation between the index of magnetic activity K and the wind velocity V is shown in Figure 4a and b.

Measurement of the Velocity of Random Movements of Irregularities

During the entire period of observations, 37 recordings with a low degree of similitude were eliminated from the total number of recordings which could be used for the determination of the wind velocity. These recordings were used to determine the velocities of random movements and the parameters connected with these movements. It is interesting to note that most of these recordings were obtained during midday and midnight hours, when no prevailing drift direction was observed and when the magnitude of the drift velocity was small. Such fadings apparently occur at a time when random movements, and not a regular drift, play a decisive role.

a. Turbidity Rate of the Ionosphere. The velocity of random movements was determined by the method described in (6,8,9). In determining the velocity, it was necessary to estimate the portion of the specular and scattered components present in the total signal reflected from the ionosphere. The measured values of β lay in a range of 0.2 to 6.5.

Higher values of β were usually observed in the E region than in the F-2 region. A specularly reflected signal was actually absent in 21 (out of 37) cases when $\bar{R}^2/\bar{R}^2 > 1.3$, i.e., in accordance with (8). Values of β could also be found in the case of 12 recordings corresponding to a case in which drift movements played a predominant part. A characteristic feature of all calculated β values is the fact that these values are related to the fading velocity. The higher the fading velocity, the smaller is the portion of specular reflection. As a rule, slow and smooth fadings were characterized by high β values (Figure 5).

b. Velocity of Random Movements V_o. Results of the measurement of velocity V_o are presented in the form of histograms shown in Figure 6a and b. In case of the E layer (Figure 6a), the velocities of random movements lie in the range of 1 to 7.5 m/sec. Most frequently V_o values of 3-4 m/sec were encountered. In case of the F-2 layer (Figure 6b), velocities of up to 24 m/sec were observed. Most frequently, V_o values of 6.7 m/sec were encountered. It was noted that the velocity of random movements increases with the altitude. This can be seen from Figure 7, which shows the relation between V_o and the reflection altitude (provided that the reflection altitude corresponds to the true level at which the movement takes place).

A value of V_o equal to 58 m/sec was obtained in processing fading recordings during the magnetic storm of 5 November 1958. One can assume that, during magnetic disturbances, the higher fading velocity of a reflected signal is connected with a higher rate of random movements of irregularities.

In addition to these 37 recordings with a low degree of similitude, 24 observation sessions with a high and medium degree of similitude were processed by the full correlation analysis method, which permits to determine the drift velocity and V_o (3). 13 of these observation sessions represented fully similar recordings, so that in all cases V_o was equal to zero. 11 recordings gave very scattered values: the lowest values amounted to 6-8 m/sec, and the highest values amounted to 29 m/sec. It is interesting to compare our V_o figures with those obtained in Cambridge (10) ($V_o \sim 20$ m/sec) and in Puerto Rice (11) ($V_o \sim 90$ m/sec). In study (6), V_o values of about 0.2-15 m/sec were obtained, and in study (7), V_o values of about 0.5-1.5 m/sec.

c. An evaluation of the size of irregularities was performed in accordance with (12). The size of the irregularities was assumed to be equal to the distance between two points on the surface of the earth, for which the correlation function $\rho(\xi)$ is reduced to the value e^{-1}.

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The spaced-aerial reception system with a base of about 100 m used in the present study permits to estimate the size of small-scale irregularities. However, it is practically impossible to obtain directly a space (steric) correlation function. Under certain assumptions (see Note), however, if the magnitude of drift velocity V and the temporary (or time) autocorrelation function $\rho(\tau)$ (this function can be plotted) are known, the horizontal dimensions ξ_0 of the irregularity can be estimated:

$$\xi_0 = \tau_0 \cdot V,$$

where $\rho(\tau) = 1/e$.

A correlation analysis of 8 recorded reflections from the E layer gave the following average dimensions of irregularities: $\xi_0 = 500$–1,500 m. The processing of 15 recorded fadings has shown that smaller size irregularities are subject to drifts in the F-2 region. On the average, $\xi_0 \sim 300$–400 m in the F-2 layer. Histograms showing the dimensions of ξ_0 for the E and F-2 layers are given in Figure 8a and b.

Electronic Analog Correlator

The electronic analog correlator was designed by V. P. Filippov at the radiophysics faculty of Tomsk University. The process involving the calculation of correlation functions during the study of ionospheric movements was simplified and accelerated with the aid of this instrument.

The amplitude fadings recorded on a photo film are converted with the aid of a photoelectronic device into electric signals $f_1(t)$ and $f_2(t)$. The computer unit (Figure 9) then performs the following operation:

$$R(\tau) = \overline{f_1(t) \cdot f_2(t+\tau)} = \frac{1}{2T} \int_{-T}^{T} f_1(t) \cdot f_2(t+\tau)\, dt,$$

where τ is the time shift prescribed by the displacement (or shift) unit.

[Note: These assumptions include, specifically, the presence of purely drift movements, and a stationary state and isotropy of the reflected diffraction picture on the surface of the earth - Editor's Note].

The time required for the calculation of the correlation function R (τ) varies from 4 to 20 minutes (depending upon the number of points in the R (τ) function). The minimum time shift, which can be achieved by means of the delay unit, is equal to 0.065 sec. The transmission band of the photoelectronic computer and of the computer unit is equal to 10 cycles - 60 kc (kilocycles). A NZ-70 A recording instrument is used as an output recording indicator of the R (τ) function; the tape transport mechanism is borrowed from a movie camera of the KA-101 type. During the calculation of R (τ), the ends of the photo film carrying the recorded fluctuations are glued together in the shape of a ring, and the unit operates in a continuous manner, computing successively the values of R corresponding to the prescribed τ values. The selection of the needed τ values is programmed by the automatic control unit. The computation error of R is less than 3%. (In contrast to the (τ) function, R (τ) is a non-normalized correlation function - Editor's note).

In conclusion, the authors wish to express their gratitude to S. F. Mirkotan, Candidate of Physical and Mathematical Sciences, for his valuable comments during the preparation of this article.

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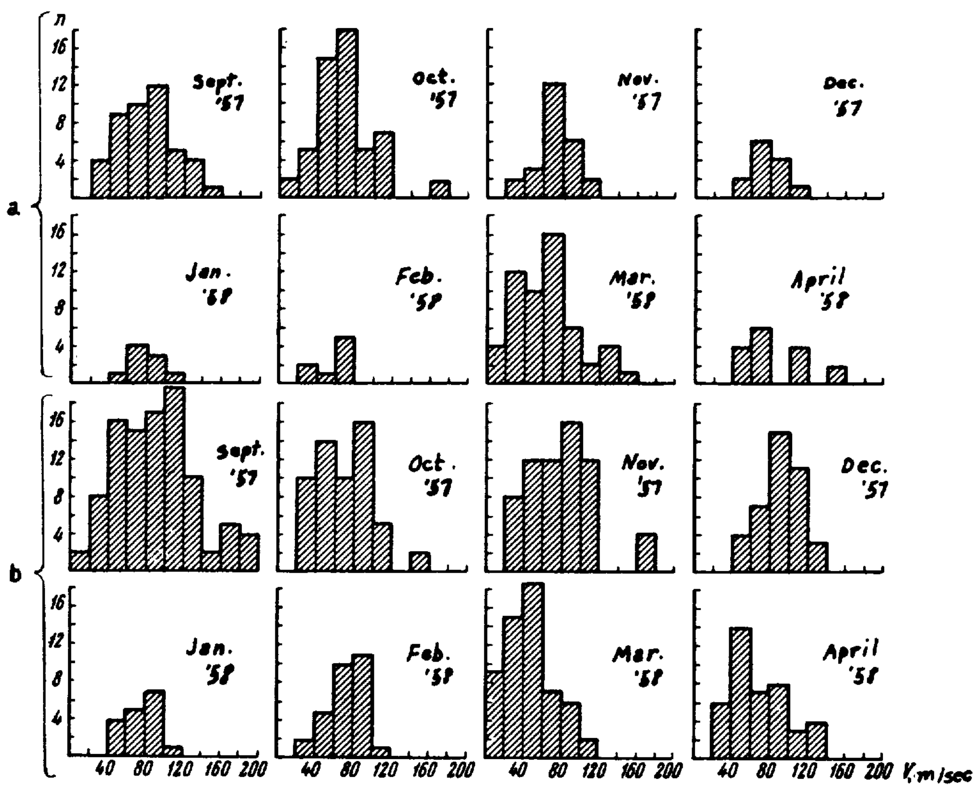

Figure 1.- Monthly histograms showing the magnitude of the drift velocity. a - for the E layer; b - for the F-2 layer; V - drift velocity in m/sec; n - number of cases.

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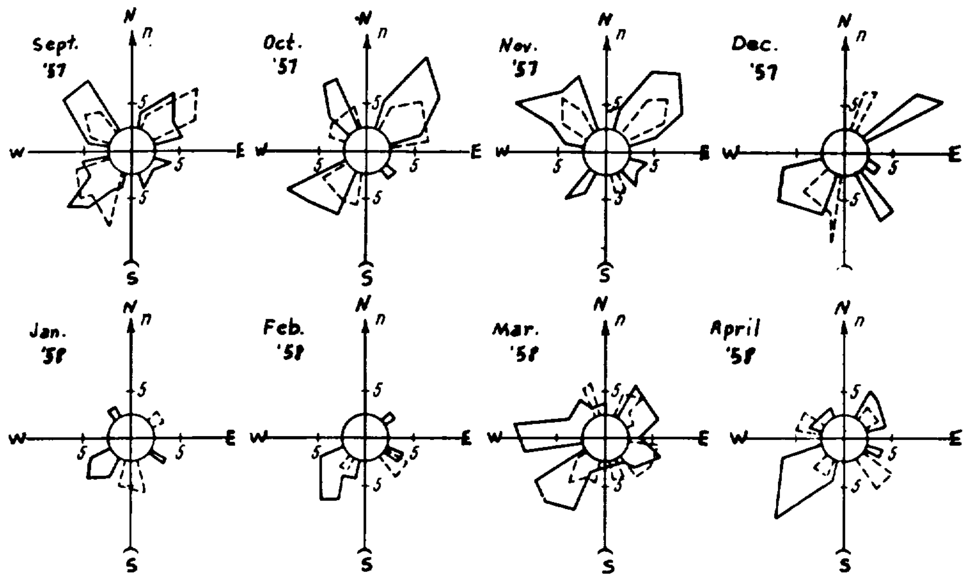

Figure 2.- Monthly histograms showing the directions of the drift velocity. Solid line - F-2 layer; dotted line - E layer; n - number of cases; NS - direction of the geographic meridian.

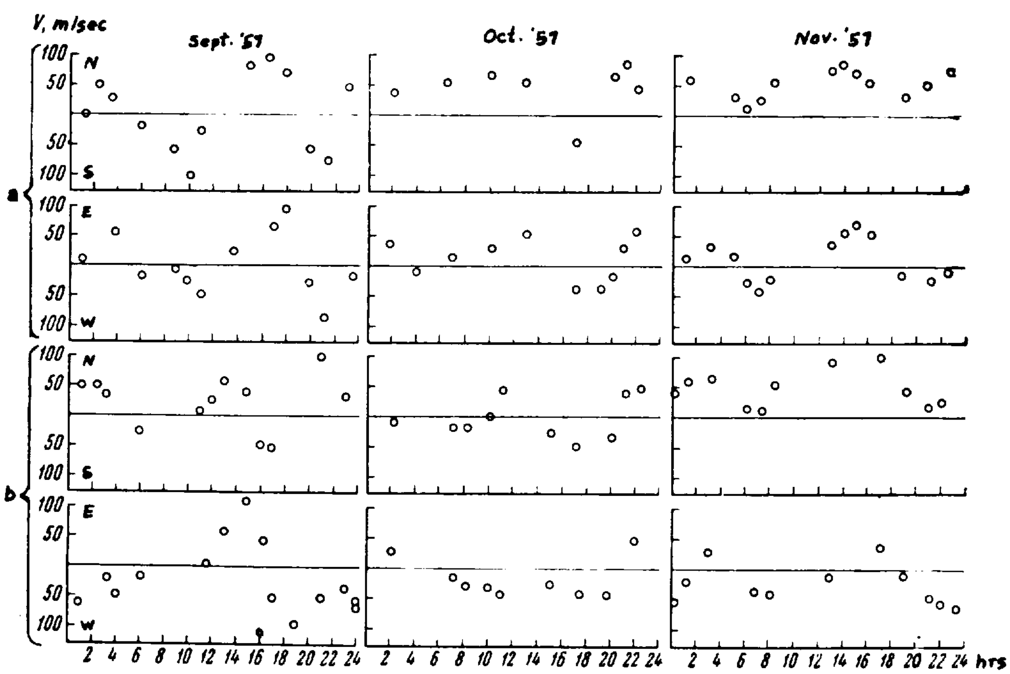

Figure 3.- Relation between the NS and EW components of drift velocity and the time of the day during September-November 1957 (average data for each month). a - E layer; b - F-2 layer.

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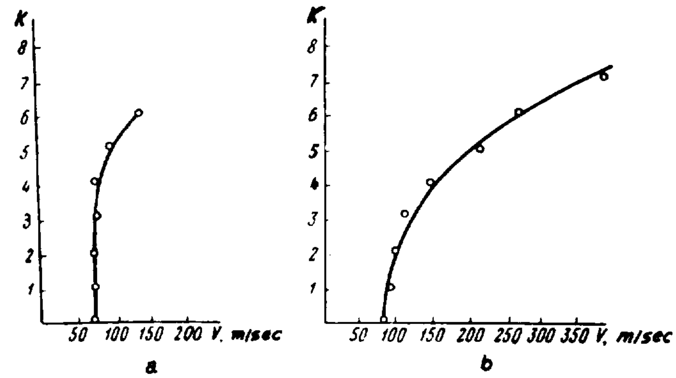

Figure 4.- Graph showing the relationship between the magnitude of drift velocity V and the index of magnetic activity K. a - E layer; b - F-2 layer.

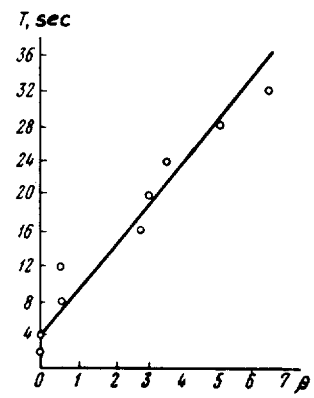

Figure 5.- Relation between the fading period T and β.

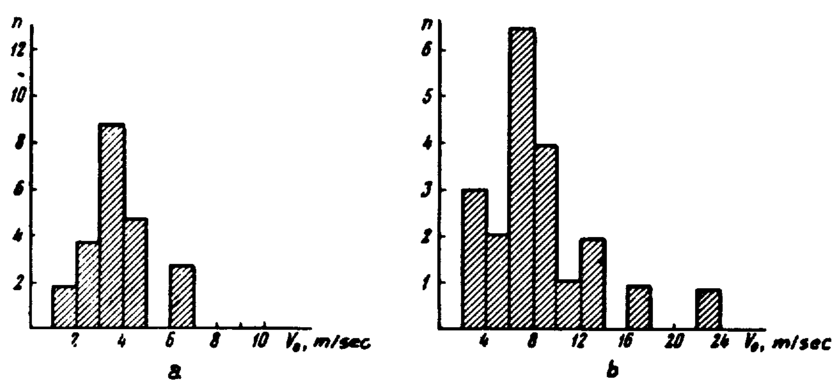

Figure 6.- Histograms of the velocities of random movements V_0. a - E layer; b - F-2 layer; n - number of cases.

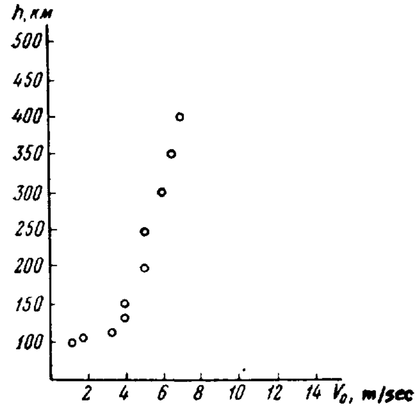

Figure 7.- Relation between the velocity of random movements and the reflection altitude h.

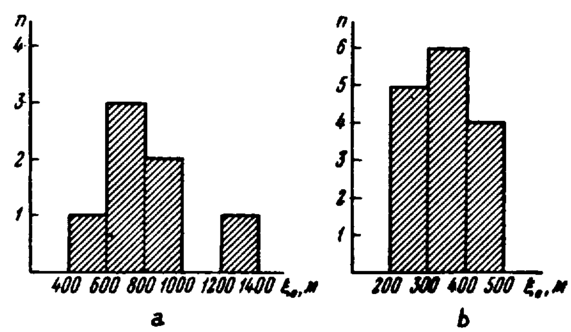

Figure 8.- Histograms of horizontal dimensions of irregularities ξ_0.
a - E layer; b - F-2 layer; n - number of cases.

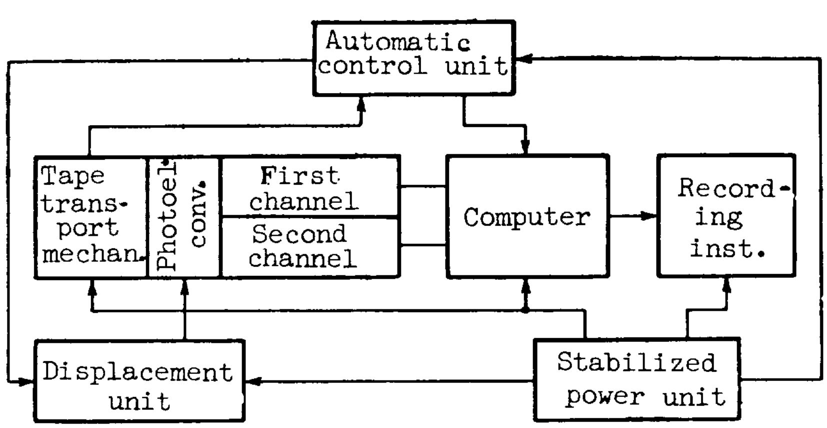

Figure 9.- Block diagram of electronic analog correlator.

F-20

SHAPE AND MOVEMENT OF SMALL IRREGULARITIES IN THE IONOSPHERE

Yu. L. Kokurin

Abstract

The correlation analysis of ionospheric irregularities shapes shows that the irregularities are in general isotropic in the plane of the
layer. Cases of essential elongation of irregularities along the lines F
of force of the earth magnetic field are very seldom observed. On 2
the ground of the analysis of diffusion and turbulence processes in the 0
ionosphere the conclusion is made that the life time of the irregularities is defined by turbulence. The velocities and directions of drift of irregularities are investigated. Data on the dependence of ionosphere state on diurnal time are obtained. Local ionospheric irregularities are observed which are regions of lower electron concentration.

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The spaced-aerial reception method is widely used in studying ionospheric winds and the irregular structure of the ionosphere. We shall examine a modification of this method, which is based on the use of radio signals transmitted by extraterrestrial sources ("radio stars"). The field of such a signal, which has traveled through an irregular ionosphere, forms a diffraction (or refraction pattern on the surface of the earth. The structure and movements of this pattern are studied by recording the signal in three (rarely more) points located on the earth at the vertex points of a triangle. At each of these points, the shifting nonuniform field is recorded in the form of signal fadings (twinkling of "radio stars"), which are displaced (shifted) in time in relation to each other. The shifting speed of the diffraction pattern, and consequently of irregularities in the ionosphere, can be determined in the first approximation from the relative time shifts of fadings at 3 points. With the aid of fading curves, it is also possible to determine the size of the diffraction spots, which, under certain conditions (1,2), correspond to the dimensions of ionospheric irregularities.

This simple method yields a correct result only under certain specific conditions, one of which is the statistical isotropy of the diffraction field on the earth (3). In general, even in the presence of a statistical isotropy of the shape of irregularities in the plane of the ionospheric layer, this condition does not apply any longer in case of an oblique incidence of the wave on the layer; this fact should be taken into account during the observation of extraterrestrial sources located near the horizon (zenith angle of about 60-90°). This condition may also not apply as a result of the anisotropic shape of the irregularities proper in the ionosphere. If this anisotropy is of a regular nature (for example, if it is connected with the earth's magnetic field), then the above-mentioned method for determining the drift velocity systematically yields incorrect results. For example, in the extreme case of irregularities stretching infinitely in a given direction, this method can only be used to determine the velocity component perpendicular to the direction of elongation. In case of a finite elongation, anisotropy corrections, which are determined by the rate of anisotropy, the mutual orientation of anisotropy axes and the velocity, must be introduced into the magnitude and direction of the drift velocity determined by the visual method. A method for making such corrections is described in (4).

Early radioastronomic measurements of drifts in the ionosphere were conducted without taking into account the possible anisotropy of irregularities. In article (5), which is devoted to a study of shapes of irregularities, it was shown, although on hand of a small number of cases (only 7), that irregularities observed by the radioastronomic method are, as a rule, strongly elongated along the lines of force of the earth's magnetic field, and that radioastronomic measurements of drift velocities in the ionosphere performed without taking anisotropy into account must therefore contain a regular error. Thus, in view of the doubtful validity of numerous experimental data on ionospheric winds obtained as a result of radioastronomic observations, it became necessary to study in detail the anisotropy of ionospheric irregularities, as well as its relation to time (days, years and phase of the solar activity cycle), to the latitude of the observation point, etc.

Similar radioastronomic observations were conducted in Australia (6) and gave the following results. During any period of the day, the degree of elongation e (the ratio between the length and the width of irregularities, expressed as an average figure derived from a large number of irregularities) varies within a range of 1 to 3-4, whereby the irregularities exhibit a random orientation during daytime, whereas at night they are mainly oriented in a North-South direction. These results differ substantially from the data obtained in England (5), in which in 3 out of 7 cases $5 \leq e \leq 20$, and in 4 cases $e \geq 20$, whereby in all cases an almost strict (with an accuracy of 1°-5°) orientation of irregularities in the direction of the lines of force of the earth's magnetic field was observed. It is possible that such a lack of agreement between the above data is due to differences in latitude of the observation points. The above statements clearly show that the problem concerning the shape of small irregularities in the ionosphere requires further study, since it is intimately connected with the problem of measuring drifts in the ionosphere. In addition, this problem is also of considerable interest from the standpoint of determining the lifetime of irregularities and clarifying the mechanism of their variability.

Determination of the Degree of Anisotropy and of Drift Velocity

The average shape of diffraction spots, formed on the surface of the earth by a radio wave which has traveled through the ionosphere, can be described in the first approximation as a characteristic ellipse formed by contours of equal amplitude or of equal field autocorrelation averaged from numerous irregularities. The degree of anisotropy of the spots or the rate of elongation will be represented by the number e, which is the ratio between the long axis and the short axis of the ellipse.

Let us examine three points 1, 2, and 3 on the surface of the earth (Figure 1). If the pattern, shown in Figure 1, is moving with a speed V, variations of the signal in time will be observed at each of these 3 points. With the aid of curves showing these variations, it is possible to plot the following functions (Figure 2):

a. The autocorrelation functions $\rho_{11}(\tau)$; $\rho_{22}(\tau)$ and $\rho_{33}(\tau)$; since the difference between these functions is not great, only one of them is actually used, for example $\rho_{11}(\tau)$.

b. The mutual (reciprocal) correlation functions $\rho_{12}(\tau)$; $\rho_{13}(\tau)$ and $\rho_{23}(\tau)$.

The space variations of the field on the earth along lines 12, 13 and 23 can be derived from the factors $\rho_{12}(0)$; $\rho_{13}(0)$ and $\rho_{23}(0)$, which are converted into the diameters of a characteristic ellipse corresponding to these directions. For this purpose, the time shifts τ'_{s12}, τ'_{s13}, τ'_{s23} are derived with the aid of the autocorrelation function, to which correspond:

$$\left.\begin{aligned} \rho_{11}(\tau'_{s12}) &= \rho_{12}(0) \\ \rho_{11}(\tau'_{s13}) &= \rho_{13}(0) \\ \rho_{11}(\tau'_{s23}) &= \rho_{23}(0). \end{aligned}\right\} \qquad (1)$$

By coupling thus in one point the auto- and mutual correlation functions, it is possible to plot the space correlation function for the above-mentioned directions; for this purpose, the time scale of the function $\rho_{11}(\tau)$ must be multiplied accordingly by the factors:

$$(V'_c)_{12} = \frac{\ell_{12}}{\tau'_{s12}}, \quad (V'_c)_{13} = \frac{\ell_{13}}{\tau'_{s13}} \quad \text{and} \quad (V'_c)_{23} = \frac{\ell_{23}}{\tau'_{s23}},$$

These factors are known as "characteristic velocities". The velocities V'_c are proportional to the diameters of the Characteristic ellipse in the corresponding directions. Thus, by assigning the values $(V'_c)_{12}$, $(V'_c)_{13}$ and $(V'_c)_{23}$ to the diameters of the ellipse, it is possible to find the ellipse itself and thus to determine the rate of elongation (e) and its direction (a) (we shall assume that (a) represents the angle, measured clockwise, formed by the short axis of the ellipse and the Northern direction).

The time shifts τ_{012} and τ_{013}, derived from mutual correlation functions (Figure 2), are used in the determination of drift velocities. The magnitude V_k and the direction φ_k of the apparent velocity (without considering the elongation) are determined geometrically by the usual method, shown in Figure 3.

The true magnitudes V and directions φ are connected with V_k and φ_k by means of the following relations:

$$\operatorname{tg}(\varphi - \varphi_k) = \frac{(e^2 - 1)\operatorname{tg}(\varphi_k - \alpha)}{1 + e^2 \operatorname{tg}^2(\varphi_k - \alpha)};$$

$$V = \frac{(V'_c)^2_{12}}{V_k} \cdot \frac{[1 + (e^2 - 1)\cos^2\alpha]\cos(\varphi - \varphi_k)}{1 + (e^2 - 1)\cos^2(\varphi - \alpha)}. \qquad (2)$$

However, the determination of V and φ is more conveniently accomplished with the aid of the graphs listed in (4).

Shape and Dimensions of Irregularities

During the period of April 1955 to February 1956, at Simeiz (44°N, 34°E), we conducted observations on two extraterrestrial sources of radio emission: Lebed' (Swan) - A ($\alpha = 19^h\ 57^m$; $\delta = 40^\circ\ 35'$) and Cassiopeia ($\alpha = 23^h\ 21^m$; $\delta = 58^\circ\ 30'$), during their upper culminations. (Note: α - straight ascension, δ - declination of the source). The straight ascensions of α - sources differ substantially, and in view of this fact it is possible to observe both daily and seasonal variations of phenomena.

The reception (see Note) of emissions on a wave with $\lambda = 6$ m was accomplished by means of 3 antennas spaced at a distance of $l_{12} = 250$ m; $l_{13} = 320$ m and $l_{23} = 300$ m (Figure 1), every day, during hours of upper culminations of the sources, in observation sessions of 1 hour duration. A sample of a recording showing variations of the signal at 3 points is shown in Figure 4 (This recording corresponds to a time interval of about 1 minute). (Note: A detailed technical description of the unit is given in [7]).

With the aid of the method described above, we determined the anisotropy of irregularities in approximately 80 cases. The distribution of the magnitude (e) in these cases is given in Figure 5, in which 10 cases, where $e \geqslant 10$, are now shown. It can be seen that the anisotropy of irregularities is substantially smaller than the one obtained in (5). The probable rate of elongation (e) is approximately equal to 1.6-1.8. Ellipses with (e) < 10 have a random orientation, which varies in each observation session, and even, as a check has revealed, during the course of individual sessions. Since the orientation may vary even within the averaging range (which, in our case, is equal to about 10-15 min) the magnitude of (e) cited above (1.6-1.8) is apparently somewhat lower than it should be. Figure 6 shows the distribution of the directions α assumed by the short axes of ellipses, and Figure 7 shows the relation between (e) and α. In those cases when $e < 5$, no grouping of directed anisotropy of any kind is observed either in the case of winter or summer variations. However, in those cases when $e \geqslant 10$, a clearly expressed grouping of directions can be observed: in 7 cases out of 10, the elongations are oriented towards the North with an accuracy of $\pm 20^{\circ}$.

Thus, it is possible to draw the conclusion that an anisotropy (e) < 5, which is mainly observed under experimental conditions, is not connected with the magnetic field of the earth, while a considerable elongation ($e \geqslant 10$), on the other hand, is caused (or determined) by this magnetic field. Consequently, quiet conditions in the ionosphere, when turbulence is so small that originally formed isotropic regions of high ionization manage to stretch out to a considerable extent, as a result of diffusion, along the lines of force of the earth's magnetic field, occur extremely rarely. We were able to observe such conditions only 10 times during a period of 11 months, whereby all cases occurred at night.

Prior to embarking on a quantitative evaluation of diffusion and turbulence, we must cite figures, required for such an evaluation, concerning the dimensions of the small-scale ionospheric irregularities investigated by us. Figure 8 shows the distribution of the magnitudes $d_m = \frac{(V'c)_{min}}{\gamma}$, where (V'c) is the minimum characteristic velocity, and ν is the repetition rate of maxima (or minima) on the recordings of the signal amplitude. The dimension d is the dimension of the irregularity along the short axis of anisotropy. The calculation of d_m was performed in the same manner as described in (8). (Editor's Note: See also the article by V. D. Gusev, S. F. Mirkotan, L. A. Drachev, Yu. V. Berezin and M. P. Kiyanovskiy published in the present symposium). The most probable magnitude of d_m is approximately equal to 1 km. No regular seasonal or daily variations in the magnitude of d_m are observed. We shall now proceed to make the above-mentioned evaluations.

First, we shall determine the diffusion which takes place along and across the magnetic field. The diffusion factors are proportional to the corresponding mobilities. For this reason, their relation is determined by the following expression:

$$\frac{D_\perp}{D_\parallel} = \frac{(v_i^n)^2}{(v_i^n)^2 + w_g^2}, \tag{3}$$

where v_i^n is the collision frequency of ions with neutral particles (the diffusion resolution of the irregularity is determined by the mobility of ions, and not of electrons), and w_g is the gyrofrequency of ions. The number of collisions v_i^n is equal to (9):

$$v_i^n = \frac{16\sqrt{2}}{3}\pi a^2 n\bar{v}, \tag{4}$$

where:

$$\bar{v} = \sqrt{\frac{8kT}{\pi M}}.$$

Let us assume that the altitude h - 300 km. For this altitude, the values of the magnitudes entering into formula (4) are as follows: $\pi a^2 = 4.3 \cdot 10^{-16}$ sq. cm. - effective cross section for air; $T = 1{,}000^\circ K$; $n \simeq 5.10^9 \div 10^{10}$ cm^{-3} - density of neutral particles; $\frac{m}{M} = 3.4 \cdot 10^{-5}$ (ions O_1). We get:

$$v_i^n \simeq 1.8$$

The gyrofrequency w_g of ions in a magnetic field H is determined by the relation:

$$w_g = \frac{He}{Mc}. \tag{5}$$

By assuming that $H \cong 0.4$ gauss; $\frac{m}{M} = 3.4 \cdot 10^{-5}$ (ions O_1), we obtain:

$$w_g \cong 240 \text{ rad/sec}$$

Thus, $\frac{D_I}{D_{II}} < 10^{-4}$. Consequently, diffusion across the magnetic field can be disregarded, and it is possible to examine the one-dimensional case of diffusion along the field. Let us assume that, at a certain time, an area of high ionization has been formed, having identical linear dimensions across and along the field. Let us approximately determine the time required for such an irregularity to stretch out along the lines of force in such a manner that $e \geqslant 10$. In this connection, we shall use the following method of evaluation. If, at the time of observation, $e \geqslant 10$, and if the density of the irregularity differs from the mean density of the surrounding medium by the magnitude ΔN_1, then we shall assume that the original moment $e \cong 1$ and $\Delta N_0 \cong 10 \Delta N_1$. Thus, the problem will involve the determination of the time required to effect a 10-fold reduction of the original excess density. Let us now solve the one-dimensional diffusion equation:

$$\frac{\partial u}{\partial t} = D \frac{\partial^2 u}{\partial x^2} \qquad (6)$$

under the initial conditions:

$$u(x,0) = N_1 \text{ at } -d_{m/2} \leqslant x \leqslant d_{m/2}; \qquad (7)$$

$$u(x,0) = N_0 \text{ at } x < -d_{m/2} \text{ and } x > d_{m/2},$$

where d_m is the previously established cross-sectional dimension of the irregularity. The diffusion factor D in equation (6) is, strictly speaking, determined by the mobility of electrons and ions in the gas. Since no data on the ambipolar diffusion factor are available at the present time, we shall only calculate this factor as it applies to ions. At the same time, in our rough estimates, we shall not take into consideration the slight increase in resolution time. We shall determine this factor by means of the formula:

$$D = \frac{0.64 \cdot 10^{20}}{n} \sqrt{T \frac{m}{M}} \text{ sq. cm} \cdot \text{sec}^{-1} \qquad (8)$$

After inserting into formula (8) the above-mentioned values of magnitudes corresponding to the altitude h = 300 km, we obtain:

$$D \cong 1.7 \cdot 10^9 \text{ sq. cm.} \cdot \text{sec}^{-1}.$$

A solution of equation (6) under the initial conditions (7) has the following appearance:

$$u(x,t) = N_0 + \frac{N_1 - N_0}{2}\left[\Phi\left(\frac{x + d_m/2}{2\sqrt{Dt}}\right) - \Phi\left(\frac{x - d_m/2}{2\sqrt{Dt}}\right)\right], \qquad (9)$$

where

$$\Phi(z) = \frac{z}{\sqrt{\pi}} \int_0^z e^{-a^2}\, da \text{ - error integral}$$

Following the selected method of evaluation, we can now determine the time τ, during which the excess density at the center of the irregularity will be reduced 10 times, i.e., let us utilize the relation:

$$0.1 = \Phi\left(\frac{d_m}{4\sqrt{D\tau}}\right). \qquad (10)$$

Using the error integral table, we find that $\tau \cong 50$ seconds. The result does not depend on the initial excess of density. Thus, a time $\tau \geqslant 1$ min is required for the formation in the ionosphere of an irregularity, having an elongation rate $e \geqslant 10$. In our experiments, the maximum factor of mutual correlation (with the exception of cases in which $e \geqslant 10$) for each of the 3 pair of recordings never exceeded 0.75-0.8, even when the direction of the drift coincided with one of the bases. This means that the lifetime of irregularities is only slightly longer than the time during which they move between antennas, i.e., their lifetime amounts to several seconds. On the average, this estimate is even higher than the real figure, since recordings with a sufficiently high degree of similitude, easily visible to the eye, were selected for correlation processing. In most cases, however, the mutual correlation of recording pairs is considerably lower than the above magnitude, and their corresponding lifetime is also shorter.

From the above, it is possible to draw the following conclusions. The lifetime of irregularities is not determined by diffusion, but rather by a different process, most likely turbulence. Quiet conditions, which are required for the formation of irregularities strongly elongated along the earth's magnetic field, are very rarely observed.

In our opinion, the fact that these results do not agree with the data presented in (5) must be attributed to the difference in latitudes of the observation points; one can therefore conclude that the turbulence rate varies to a considerable extent with the latitude.

Velocities and Directions of the Drift of Irregularities

The distribution of the true velocity magnitudes of the movement of irregularities V (see Note) is shown in Figure 9. (Note: During the calculation of these velocities, a correction was introduced, which was connected with the rotation of the earth, and which was equal, on the average, for both "radio stars" to V_{EW} = 15 m/sec.). As can be seen, in most cases these velocities lie in a range of 40-160 m/sec. The most probable magnitude of V is equal to about 100 m/sec, which represents the usual velocity of the drift and which is in agreement with other experimental data. Analysis has shown that there is no substantial relation between the magnitude of V and the time of day and year.

Figure 10 shows the distribution of drift directions φ. Inspite of the fact that this distribution is very wide, a concentration of velocities mainly in the Southern semicircumference may be noted. An examination of such a distribution, plotted separately on the basis of night time and daytime data, shows that a grouping of velocities in the Southern semicircumference is observed primarily at night, while the velocity directions are distributed in a haphazard manner during daytime.

It is not possible to compare this result with the results of other studies since the latter were conducted at different latitudes. It is merely possible to note that our data differ substantially from the data obtained at latitudes of about 30° S (6) and 70° N (10, 11, et al.,), which also do not agree with each other.

Daily Course of Blinking

In order to clarify the relationship between the status of the ionosphere and the time of the day, the ratio between $n_m/\sum$ of the number of sessions during which blinking of the sources was observed, and the total number of observations was determined for each hour of the local time. This ratio expresses the probability of the appearance of blinking. The nature of the relationship between $n_m/\sum$ and local time was found to be identical for both sources. This means that the time course of $n_m/\sum$ is a daily course, and not a seasonal course, since the straight ascensions of the sources are substantially different.

This course, plotted on the basis of observation data obtained from both sources, is shown in Figure 11. This course is characterized by the presence of a sharp night maximum and of a small blurred maximum corresponding to daytime hours. Thus, the disturbed condition of the ionosphere, observed by the radioastronomic method, occurs mainly at night. This fact causes certain difficulties during the study of the daily course of characteristics of an irregular ionosphere (e, α, d_m, V, φ and others), since information available on these magnitudes is considerably poorer during daytime hours than at night.

Local Irregularities

In a number of cases, we observed transitions of the ionosphere from a quiet condition to a disturbed condition. Such periods are characterized by the presence in the ionosphere of local irregularities, which arise at first in isolated instances, then in groups, and finally result in the formation of solid fields. This process may be interpreted in two ways:

1. It may coincide with the passage over the point of observation of the edge of a disturbed area in the ionosphere; whereby the edge of the area must not be sharply outlined, but should appear blurred.

2. If we are dealing with an actual growth of the disturbance, this process must then be of a gradual nature; it is interesting to note that the reverse process, namely a decrease of the disturbance, has never been observed; from this fact, it is possible to conclude that the process involving a decrease of the disturbance occurs at a considerably slower rate than the growth process, and that the second mechanism is more probable than the first one.

The above-mentioned local irregularities have the characteristic shape of a spot ("dark" or "bright"), surrounded by a number of diffraction maxima and minima (Figure 12). Such a picture corresponds to the presence of a separate lens in the ionosphere. We must note, however, an interesting fact: namely, that these lenses are, in the great majority of cases, focusing lenses, i.e., they constitute areas of reduced electron concentration.

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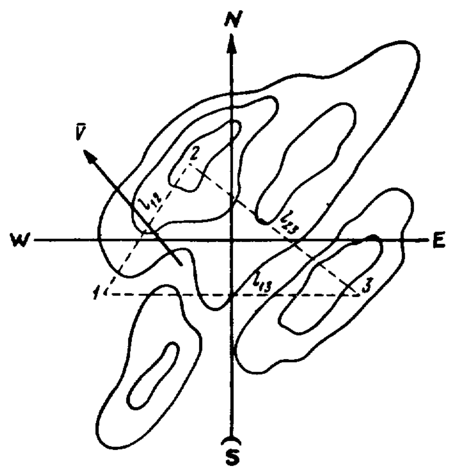

Figure 1.- Contours of equal field amplitude.

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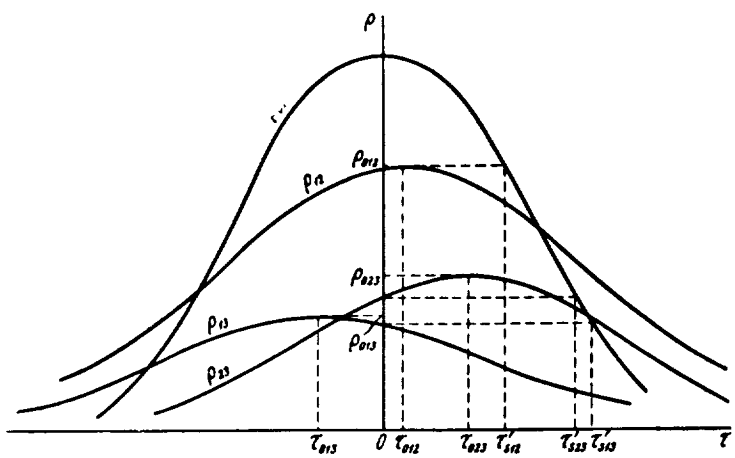

Figure 2.- Auto- and mutual-correlation functions.

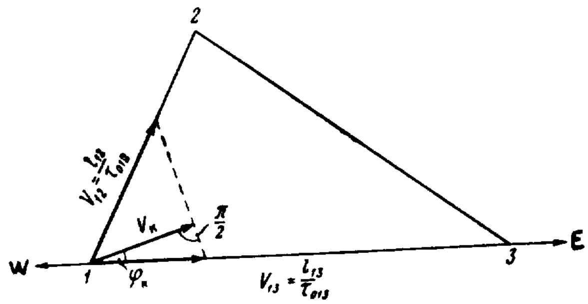

Figure 3.- Graphic method for determining the apparent magnitudes of velocity V_k and its directions.

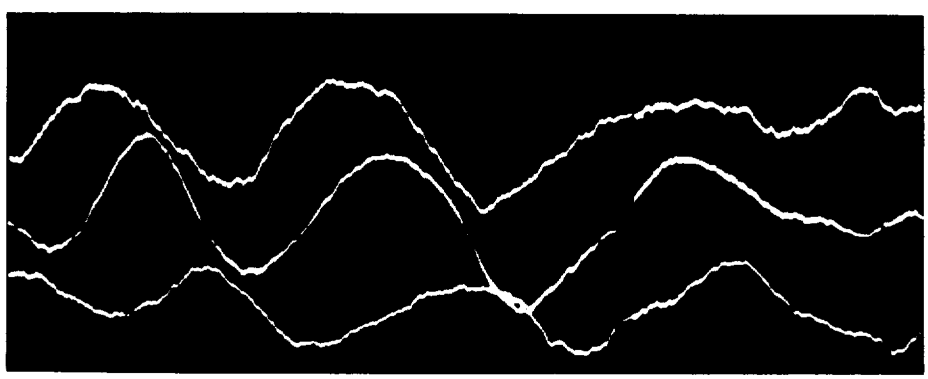

Figure 4.- Recording of a signal from the Lebed' (Swan) - A "radio star." Date: 30 June 1956.

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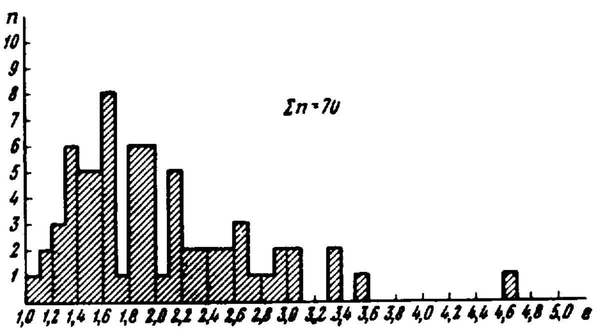

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Figure 5.- Distribution of the anisotropy rate e.

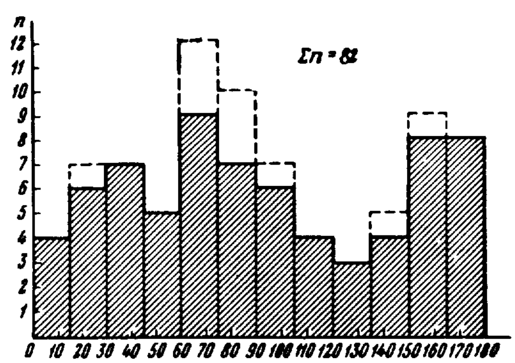

Figure 6.- Distribution of the directions of elongation α (cases in which $e \geqq 10$ are shown by means of dotted lines).

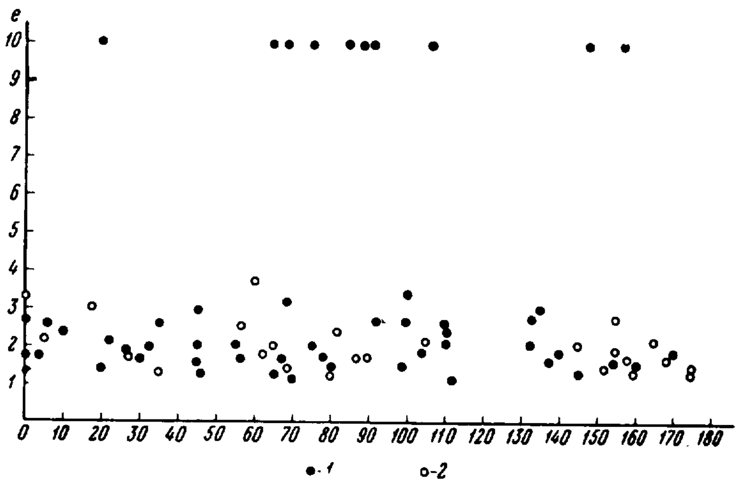

Figure 7.- Relation between e and α. 1 - Summer observations; 2 - Winter observations.

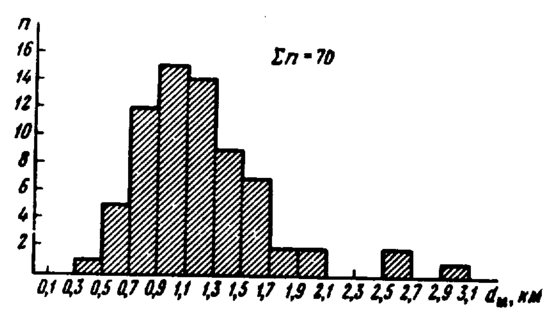

Figure 8.- Distribution of cross-sectional dimensions d_m of irregularities.

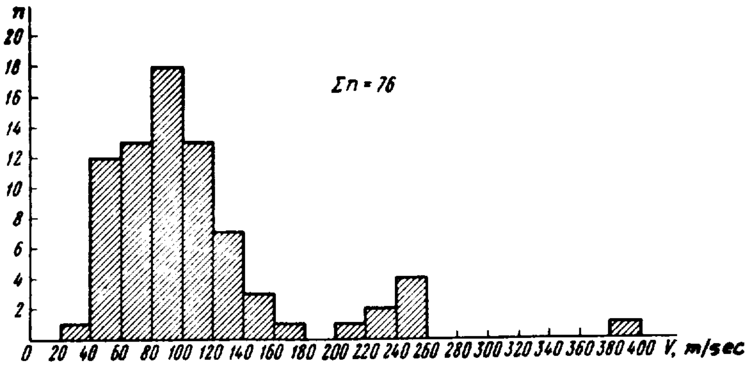

Figure 9.- Distribution of the magnitudes of drift velocity V.

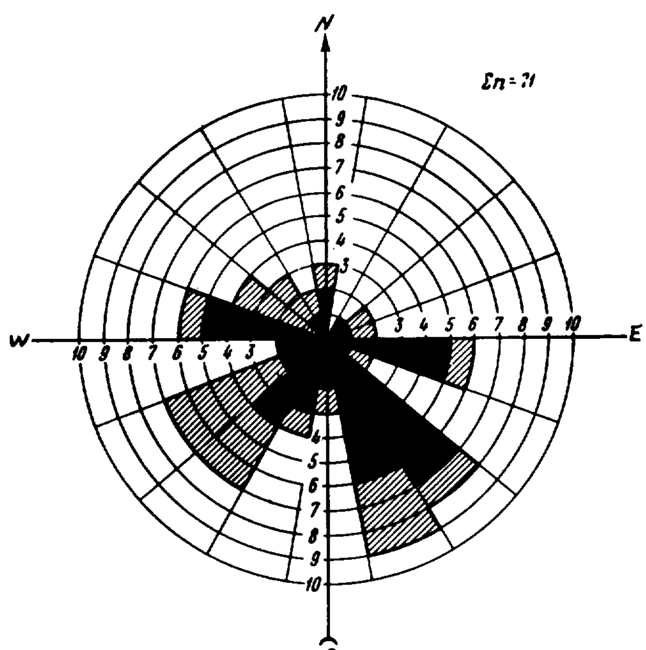

Figure 10.- Distribution of drift directions φ. The shaded area refers to night data, and the unshaded area refers to daytime data.

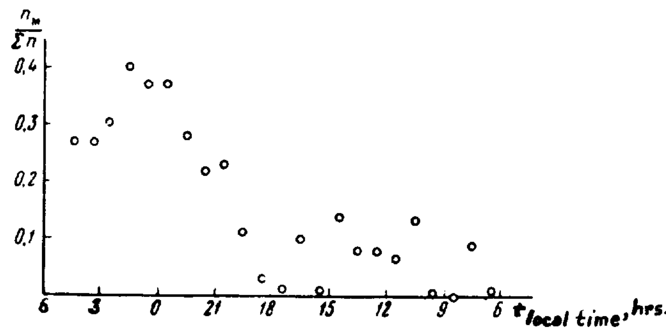

Figure 11.- Daily course of the probability of the appearance of blinking.

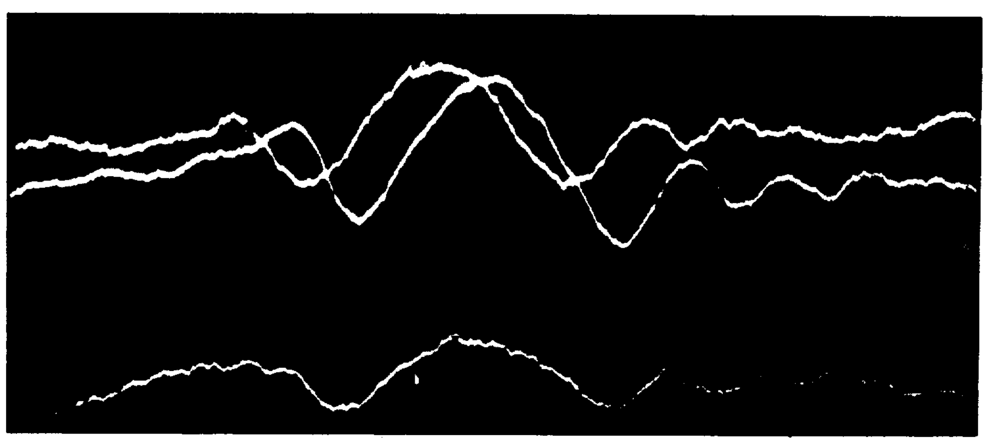

Figure 12.- Sample of a local irregularity. Recording of a signal from the Lebed' (Swan) - A "radio star." Date: 23 August 1956.

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